BARLEY SILAGE OR CORN SILAGE FED IN COMBINATION WITH BARLEY GRAIN, CORN GRAIN, OR A BLEND OF CORN AND BARLEY GRAIN FOR FINISHING BEEF CATTLE

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ABSTRACT

The objectives of the current studies were to evaluate the effects of silage (**S**) and cereal grain (**G**) source and their interaction (**S × G**) on growth performance, digestibility, and carcass characteristics (Study 1) and dry matter intake, ruminal fermentation, total-tract digestibility, and nitrogen balance (Study 2) for finishing beef cattle. For Study 1, 288 steers weighing 465 ± 28 kg were randomly assigned to 1 of 24 pens (12 steers/pen) in an 89-d finishing study. Study 2 used five ruminally cannulated heifers in an incomplete 6 × 6 Latin square design. Periods were 25-d in duration with 5 d of diet transition, 13 d of dietary adaptation, and 7 d of sample collection. Dietary treatments for both studies included corn silage (**CS**) or barley silage (**BS**) at 8% of DM. Within each silage source, diets contained dry-rolled barley grain (**BG**; 86% of DM), dry-rolled corn grain (**CG**; 85% of DM), or an equal blend of barley and corn grain (**BCG**; 85% of DM). In Study 1, there were no interactions between silage and cereal grain source ($P \geq 0.10$). Feeding CG increased (G, $P < 0.01$) DMI by 0.8 and 0.6 kg/d relative to BG and BCG, respectively. Gain-to-feed was greater (G, $P = 0.04$) for BG (0.17 kg/kg) than CG (0.16 kg/kg), but not different from BCG (0.17 kg/kg). Furthermore, average daily gain (2.07 kg/d) and final body weight were not different among treatments ($P > 0.05$). Hot carcass weight was 6.2 kg greater (372.2 vs. 366.0 kg; S, $P < 0.01$) and dressing percent was 0.57% greater (59.53 vs. 58.96 %; S, $P = 0.04$) for steers fed CS than BS, respectively. In Study 2, DM intake and mean pH were not affected by diet. Total SCFA concentrations were greater for BCG than BG or CG (G, $P < 0.01$) and for CS (S, $P < 0.01$) relative to BS. Molar proportion of acetate was increased for BS-BG and BS-CG (S × G, $P < 0.01$), while molar proportion of propionate was greatest for CS-BG (S × G, $P < 0.01$). Rumen ammonia-nitrogen concentrations were greatest for CG (G, $P < 0.001$), and higher for CS than BS (S, $P = 0.02$). Apparent total-tract digestibility of DM, OM, aNDFom, starch and gross energy were greatest for BG (G, $P \leq 0.04$). Dietary digestible energy content (Mcal/kg) was greatest for BG treatments (G, $P = 0.03$). Total nitrogen retention (g/d and % of intake) was greatest for CS-BG (S × G, $P \leq 0.03$). The potentially degradable fraction of DM, CP, and starch were greater for CG ($P \leq 0.03$) than BG. For silage sources, CS had greater 24, 48 and 72-h starch digestibility ($P \leq 0.03$) relative to BS. These results indicate that feeding dry-rolled BG may improve performance and digestibility when compared to CG and BCG and CS may provide benefits over BS. Improvements related to feeding BG and CS may be due to greater propionate production, improved nutrient digestibility, and greater N retention.

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LIST OF ABBREVIATIONS

ADF = Acid detergent fibre

ADG = Average daily gain

aNDFom = NDF assay with amylase and sodium sulfite, corrected for ash content

BCG = Blended grain treatment with 50:50 ratio of corn and barley grain

BG = Barley grain

BMR = Brown midrib corn

BS = Barley silage

BW = Body weight

CG = Corn grain

CHU = Corn heat units

CP = Crude protein

CS = Corn silage

CVAS = Cumberland Valley Analytical Services

DE = Digestible energy

DIP = Degradable intake protein

DM = Dry matter

DMI = Dry matter intake

ED = Effective degradability

G = Grain effect

G:F = Gain to feed

GE = Gross energy

INDF = Indigestible neutral detergent fibre

LAB = Lactic acid bacteria

ME = Metabolizable energy

N = Nitrogen

NASEM = National Academy of Sciences, Engineering, and Medicine

NDF = Neutral detergent fibre

NDFD = Neutral detergent fibre digestibility

NE = Net energy

NE_g = Net energy of gain

NE_L = Net energy of lactation

NE_m = Net energy of maintenance

NIR = Near infrared spectroscopy

NP = Not present

NRC = National Research Council

OM = Organic matter

PD = Purine derivatives

peNDF = Physically effective fibre

PI = Processing index

RE = Retained energy

S × G = Silage by grain interaction

S = Silage effect

SD = Standard deviation

SEM = Standard error of the means

TCL = Theoretical chop length

TDN = Total digestible nutrients

USDA = United States Department of Agriculture

WSC = Water soluble carbohydrates

1.0 GENERAL INTRODUCTION

Barley is an important cereal grain and forage crop grown in western Canada. In terms of cereal grain production, barley ranked third in Canada with 2.99 million hectares seeded in 2019, 92.5% of which was seeded on the prairies (Statistics Canada, 2019a). However, nearly 70 to 80% of barley produced does not meet malting grades and is diverted to use as livestock feed (SaskBarley Development Commission, 2019). In addition, forage barley varieties are commonly grown for production of silage or green feed. Barley grain offers moderately high energy levels and is greater in crude protein relative to corn grain (National Academy of Science, Engineering, and Medecine (NASEM), 2016). Given the regional suitability, nutrient content, and availability of barley grain and forage, barley has become a staple feed for the western Canadian cattle feeding industry.

Due to the high energy content of starch, cereal grains constitute a major portion of finishing diets. Increasing dietary energy content by provision of cereal grains generally improves feed efficiency and lowers the cost of gain (Gibb et al., 2009). However, decreasing yields of barley grain in recent years has reduced global stocks and subsequently increased the price of barley grain (Statistics Canada, 2019a). Though Canadian acreage of barley has increased in response to demand (Statistics Canada, 2019a), higher feed prices have stimulated interest in other grain sources for finishing diets. In combination with the interest in alternative grain sources in western Canada, growth in the planted corn acreage has increased availability and interest in production of corn for livestock feed.

Ongoing development of short-season corn varieties that are capable of reaching maturity earlier than conventional corn varieties has increased production of corn grain in western Canada. Though the majority of corn grain production on the prairies occurs in Manitoba, there is an increasing availability of corn grain for cattle feed on the Prairies (Statistics Canada, 2018a). In circumstances where corn and barley prices are similar, it may be cost effective to feed corn as an alternative. But, as the corn-feeding industry is still relatively new in western Canada, there is limited research comparing the differences in feedlot performance of cattle fed corn compared to barley. In order to maximize the digestibility of starch in corn grain, steam-flaking is the recommended processing method; while for barley grain, digestibility can be maximized with dry- or temper-rolling. Since barley grain has long been used in western Canada, roller mills and tempering systems are commonplace at most feed yards, but technology required to maximize digestibility of corn grain is currently not readily available. Thus, corn used in western Canada is still largely dry-rolled or temper-rolled: practices that may not optimize starch digestibility.

As a forage source, corn silage may provide substantial yield advantages when compared to barley (Lardner et al., 2017). In addition, recent studies evaluating short season corn varieties have reported that under adequate growing conditions, corn silage may contain up to 30% starch, much greater than the starch content typically present in barley silage (Baron et al., 2014; Chibisa and Beauchemin, 2018). Though there is still substantial risk associated with corn production on the prairies in years where the growing season is shortened and there is little precipitation, these short-season corn varieties are leading to expansion in corn acreage on the prairies.

The objective of this literature review is to provide an overview of the production of cereal grain and silage in western Canada with specific focus on current research regarding differences between corn and barley as silage and grain sources for finishing cattle.

2.0 LITERATURE REVIEW

2.1 Cereal Grains

2.1.1 Cereal Grain Production in Western Canada

The principal crops produced throughout Canada for grain and oilseed production include wheat, canola, barley, corn, and oat (Statistics Canada, 2019b). Due to the large variation in climate across Canada, regional suitability largely dictates the predominant crops grown in each province. As well, Canada is a leading global producer and exporter of malt barley, flaxseed, canola, pulses, oat, and durum wheat (Grain Growers of Canada, 2017), with the majority of grain production occurring in the three western prairie provinces.

Within Alberta, Saskatchewan, and Manitoba, wheat and canola are the top two crops in terms of the quantity of produced. With a production of 31.8 million tonnes for 2018 and 9.53 million seeded hectares for 2019, wheat remains Canada's largest cereal grain crop, down a marginal 0.8% from 2018 (Statistics Canada, 2018b; Statistics Canada, 2019a). Though canola is still the second highest produced crop with a total of 8.48 million seeded hectares in 2019, national canola acreage has been reported as the lowest since 2016, down 8.2% from 2018, and is being attributed to ongoing trade disputes that are limiting trade access to Chinese markets as well as high global oilseed production (Statistics Canada, 2019a).

Ranking 3rd in production quantity, barley is a major cereal grain crop grown in western Canada. Low global stocks have increased demand and subsequently prices for barley grain in recent years, potentially prompting the 14.0% increase in acreage for 2019 (Statistics Canada, 2019a). In Alberta, barley is the third greatest crop produced with 1.4 million of Canada's total 2.99 million hectares seeded in 2019, with the three prairie provinces accounting for 95.2% of Canada's seeded barley area in 2019 (Statistics Canada, 2019a).

While wheat, canola, and barley are the primary crops produced in western Canada, the same can be said for corn in eastern Canada. Corn grain acreage was reported to be up 1.9% to 1.50 million hectares in 2019, the majority of which (1.28 million hectares) was planted in Ontario and Quebec (Statistics Canada, 2019a). Of the western Canadian provinces, Manitoba has the largest share with 186,074 hectares of corn for grain production seeded in 2019, while Alberta and Saskatchewan reported only 11,776 and 7,082 hectares, respectively, although these values have been slowly increasing in recent years (Statistics Canada, 2019a).

Though a smaller contributor to the cattle feeding sector, there is an estimated 18.1% increase in 2019 acreage of oat to 1.45 million hectares, the majority of which is due to increases in seeded acres in Saskatchewan (Statistics Canada, 2019a). Similar to barley, low availability and an anticipated increase in demand for livestock feed may have motivated this increase in acreage.

2.1.1.1 Cereal Grain Use for Feed

Cereal grains such as barley, corn, and wheat are the predominant grain sources in finishing beef cattle diets (Owens et al., 1997). Aside from the cost of purchasing cattle, feed is one of the most significant expenses associated with producing livestock. As a result, the type of grain used in finishing diets is largely based upon price and availability, and may have a large impact on operation profitability. In Canada, the most common feed grains include barley, wheat, corn, and oats. In the United States however, corn grain is by far the most common feed grain, accounting for 96.2% of grain produced for feeding purposes, followed by sorghum and to a lesser extent, barley (United States Department of Agriculture (USDA), 2018). However, increases in corn grain production and the sometimes competitive pricing of corn relative to barley, has increased the use and availability of corn grain for feed in western Canada.

Barley grain is typically classified based on its end use being either for malt, feed, or food purposes. Barley varieties can be found as either 2- or 6-row varieties and either hulled or hull-less. However, the latter only accounts for <1% of total production and is generally used for human food production (O'Donovan, 2015). The major difference between 2- and 6-row barley is the arrangement of kernels within the head of the plant. Two-row varieties produce fewer kernels, but allow more room for growth, resulting in larger kernels with a greater starch content (O'Donovan, 2015). The intended goal of barley grain production is generally to achieve malting standards, which sell at a higher price than feed-grade barley as it is used for brewing. Of the 8.4 million tonnes of barley harvested in 2018, nearly 2 million tonnes were exported for malting purposes and around 300,000 tonnes were used domestically within the brewing industry (SaskBarley Development Commission, 2019). Barley that falls below malting standards is diverted towards use as feed, which can account for 70 to 80% of annual barley production (SaskBarley Development Commission, 2019). Due to the large production of barley grain in the prairie provinces of Canada, it is generally the most common grain used in feedlot diets in that region.

Moreover, as nearly 60% of Canada's feeder cattle are in Alberta, it is no surprise that the greatest provincial acreage of barley is also grown in Alberta (Statistics Canada, 2017).

The vast majority of corn for grain production is grown in eastern Canada (Statistics Canada, 2019b). However, recent development of short-season hybrid corn varieties has expanded corn grain production into the southern regions of western Canada. Some of the short-season corn varieties are capable of reaching maturity at < 2200 corn heat units (**CHU**; Baron et al., 2003; Guyader et al., 2018). In 2018, average corn yields in Canada were 9.59 tonnes/ha (154.6 bu/ac), though yields are generally lower in western Canada. Due to the high yield potential, growth of the corn grain industry on the prairies could be significant, though risks associated with low precipitation and short growing seasons may still limit adoption. Corn produced in Canada is generally grown as corn for grain, corn silage, or sweet corn. Of the Canadian corn grain production, over half of the domestic consumption was used as livestock feed (Statistics Canada, 2018a). In western Canada, the largest markets for corn grain are as livestock feed or for ethanol production, although a small portion of grain production is also consumed by humans. Expansion of the corn grain industry in Manitoba was partially due to increased feed demand due to growth of the hog industry, a large corn consumer, as well as increased ethanol production. Corn by-products of ethanol production such as distillers' grains also contribute to the feed market.

While corn and barley are generally the most important feed grains, wheat and oat also comprise a portion of the feed grain industry in western Canada. Wheat that fails to meet quality grades established for flour milling is often utilized as feed. The majority of feed wheat is used for swine and poultry diets, although use in feedlots is increasing and a number of studies have purposely evaluated the use of wheat in finishing beef cattle diets (Axe et al., 1987; Bock et al., 1991; He et al., 2015) or provided information on the use of wheat when producers incorporate it into their diets due to favourable market conditions (Wiese et al., 2017). Additionally, by-products arising from wheat cleaning and wheat-based ethanol production are commonly used in livestock diets. Oat grain is generally used for feed or human consumption. Of feed oat, the most desirable class are pony oats, which demand a higher price as they are fed in the racehorse industry, as opposed to feed oats which range in quality and are generally fed to non-competitive horses and calves (Prairie Oat Growers Association, 2016).

2.1.2 Physical Structure of Corn and Barley Grain

The cereal grain structure has a large impact on digestibility of nutrients and the required processing of the grain for efficient utilization by cattle. The barley grain kernel is composed primarily of 5 layers (Figure 2.1): husk; pericarp; testa; aleurone; and endosperm (MacGregor, 2003). The husk is the outermost structure of the barley grain kernel and in hulled varieties is tightly bound to the pericarp. In hull-less varieties, the husk is loosely attached and can be easily removed during harvesting. The husk is highly resistant to digestion and thus often requires processing to enable digestion of starch within the endosperm. The pericarp surrounds the testa, which comprise the seed coat layer. Together, the husk, pericarp and testa comprise the fibrous portion of the barley kernel and can account for up to 25% of the kernel weight (O'Donovan, 2015). The remainder of the grain kernel is composed primarily of starch and protein. The aleurone is a very thin protein layer within the seed coat that encases the endosperm. The endosperm of the barley grain kernel contains starch granules. Starch granules in barley grain are arranged in a protein matrix, but intermolecular bonds between starch and protein do not resist digestion to the same extent as in corn.

For corn grain, the prominent types produced are flint and dent corn, with dent corn being more popular in North America. The two varieties differ primarily in their endosperm texture and vary greatly in the extent of ruminal starch degradability, with flint corn having more than 20% less *in situ* ruminal degradability than dent corn when ground to 3-mm (Philippeau et al., 1999b; Philippeau et al., 1999a). Corn grain contains aa bran composed of the pericarp and seed coat, a germ, endosperm, and tip cap (Figure 2.2). The hull is covered in wax and, with the bran, composes approximately 5 to 6% of the kernel weight. The germ of the corn kernel accounts for 10 to 14% of the kernel weight, while the remaining portion of the kernel is comprised entirely of the starchy endosperm (Delcour and Hoseney, 2010). Starch contained within the endosperm is generally classified as being floury or vitreous. Vitreous starch (or horny endosperm) is generally found along the outer edge of the endosperm and is translucent in color with starch granules that are tightly compacted within a protein matrix. Floury starch (or floury endosperm) is opaque in color due to more loosely condensed starch granules. Flint corn contains a larger portion of vitreous starch, while dent corn contains primarily floury starch. Hybrid varieties are often a combination of dent and flint corn and thus generally contain some amount of vitreous starch. Popcorn varieties are nearly entirely composed of vitreous starch.

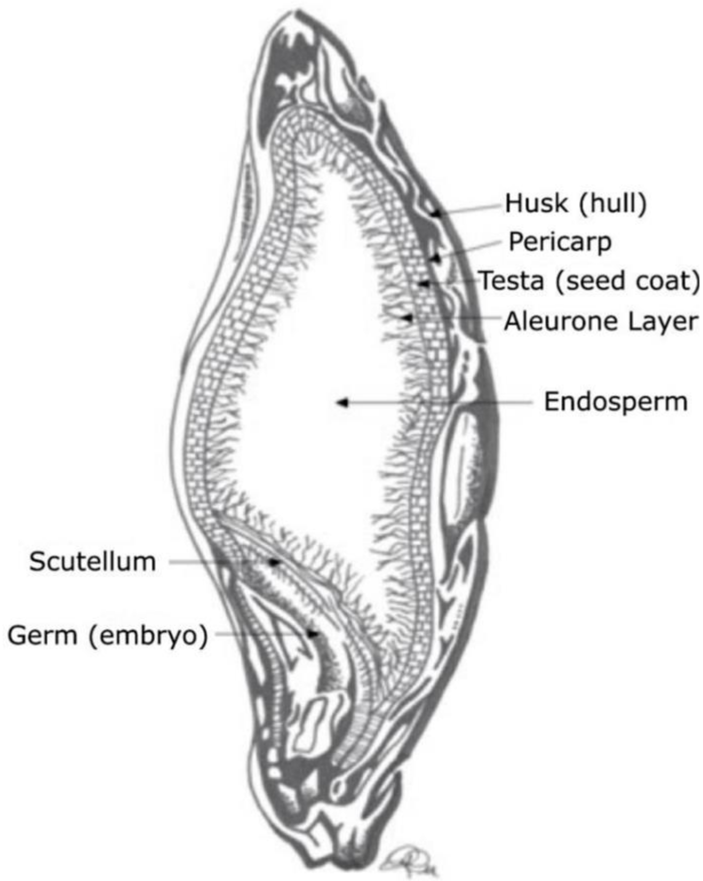

Figure 2.1 Schematic cross section of a barley kernel, adapted from Buglass et al. (2010).

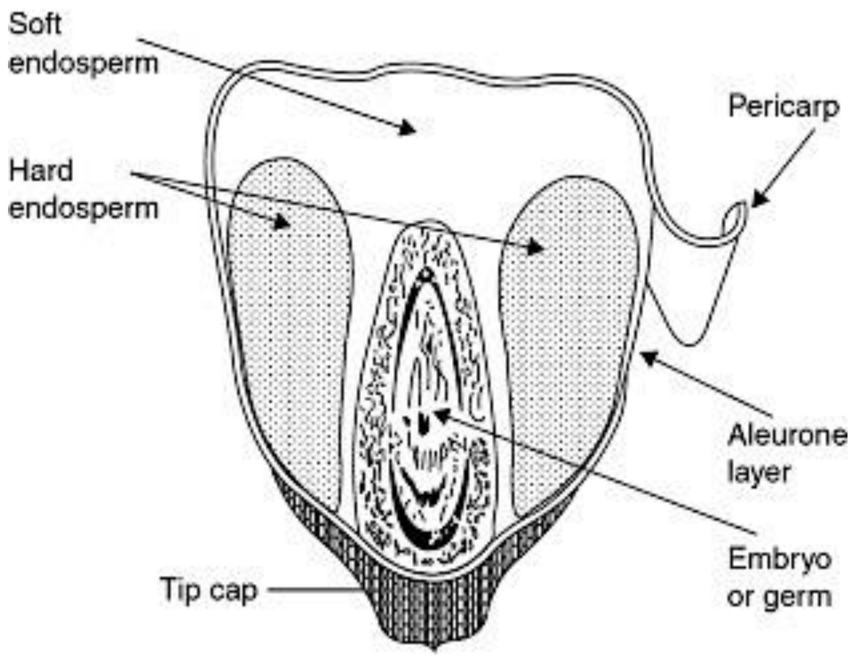

Figure 2.2 Schematic cross section of a corn kernel, adapted from Scott and Emery (2016).

2.1.3 Chemical Composition of Corn and Barley Grain

The chemical composition of corn and barley grain largely reflects the structure of each respective grain kernel. Chemical composition of samples of barley and corn grain from western Canada and corn grain for the Upper Midwest US analyzed by Cumberland Valley Analytical Services (CVAS; 2019) from January 1, 2014 to January 1, 2019 are presented in Table 2.1. The smaller kernel size and the large and fibrous outer hull of the barley kernel contribute to the greater acid detergent fibre (**ADF**) and neutral detergent fibre (**NDF**), and lower starch content of barley grain relative to corn grain. These differences in fibre and starch content account for the lower energy value for barley grain. Though corn may have a greater starch content than barley, the starch present in corn grain is resistant to digestion due it being embedded within a complex protein matrix, while starch present in barley grain is more rapidly degraded (Herrera-Saldana et al., 1990; Ferreira et al., 2018). The greater level of fat in corn grain relative to barley also contributes to its greater energy content, given that lipid has approximately 2.25 times the energy density of carbohydrates.

Greater total digestible nutrients (**TDN**), net energy of maintenance (**NE_m**), and net energy of gain (**NE_g**) for corn grain indicate a greater energy value than that of barley. While corn grain may have a greater energy content, crude protein (**CP**) content is generally much greater in barley grain. Additionally, similar to the availability of starch, the protein present in corn grain is complexly arranged and often unavailable to a large extent. As a result, diets based on corn grain often requires additional protein supplementation to meet the CP requirements of backgrounding and finishing cattle, while barley grain diets may meet requirements without the need for supplementation (Galyean, 1996).

2.1.3.1 Amylose and Amylopectin

Starch is the primary carbohydrate supplied by cereal grains and is structurally composed of two types of glucose polymers: amylose and amylopectin. Amylose is composed of up to 3000 linear glucose molecules linked by α-1,4 bonds (Takeda et al., 1993), while amylopectin is composed of a backbone of α-1,4 bonded glucose units with α-1,6 branch points (Zobel, 1988). Cereal grains with starch granules containing low (< 15%) amylose are considered waxy, ranges from 16 to 35% are considered normal, and when amylose content is greater than 36%, grains are considered to be high-amylose (McAllister and Ribeiro, 2013). The waxy gene is present in a

Table 2.1 Nutrient composition (mean ± SD) of Canadian barley and corn grain and Upper Midwest US corn grain as reported by Cumberland Valley Analytical Services (2019)[1].

	Western Canada[2]		Upper Midwest US[3]
	Barley grain	Corn grain	Corn grain
OM, % DM	97.0 ± 0.75	98.3 ± 0.80	98.6 ± 0.39
CP, % DM	12.4 ± 1.56	9.2 ± 1.49	8.4 ± 1.04
Starch, % DM	59.9 ± 5.84	71.1 ± 7.82	73.2 ± 3.32
ADF, % DM	7.2 ± 2.64	5.7 ± 6.29	4.5 ± 1.45
NDF, % DM	17.8 ± 4.23	12.5 ± 9.66	10.6 ± 2.68
Fat, % DM	2.3 ± 0.50	3.7 ± 0.68	3.9 ± 0.61
TDN, % DM	80.4 ± 2.34	85.2 ± 4.72	86.0 ± 1.30
NE_m, Mcal/kg	1.96 ± 0.07	2.09 ± 0.15	2.12 ± 0.04
NE_g, Mcal/kg	1.30 ± 0.07	1.43 ± 0.13	1.46 ± 0.02

[1]Values reported from January 1, 2014 to January 1, 2019.
[2]For Canadian barley grain n ≥ 1,161; for corn grain n ≥ 564.
[3]For Upper Midwest US corn grain n ≥ 4,899.

number of cereal grains including corn and barley, and is the result of a mutation in the genes responsible for granule bound starch synthase, which is an essential component for the synthesis of amylose (Rahman et al., 2000). Amylose forms a helix or double-helix structure that makes it more resistant to digestion (Buléon et al., 1998). Cereals with high amylose content have been observed to be resistant to gelatinization during processing, and are prone to retrogradation when stored at high temperatures (Svihusa et al., 2005). Retrogradation of amylose occurs more rapidly than for amylopectin, and involves the breaking and reformation of molecular bonds of amylose molecules which are stabilized by hydrogen bonds and are more resistant to digestion (Eerlingen et al., 1994).

In monogastrics, a number of studies have demonstrated a negative association between amylose:amylopectin ratio and starch digestibility (Bednar et al., 2001; Svihusa et al., 2005). For ruminants, there is a limited amount of research regarding the effects of low or high amylose grain varieties on starch digestibility. For corn, Philippeau et al. (1998) found no effect of amylose:amylopectin ratio on ruminal starch degradation. Another study by Akay et al. (2002) demonstrated an increase in ruminal starch degradation for waxy compared to conventional corn varieties. For barley, Damiran and Yu (2010) demonstrated that effective degradability of starch increased with increasing amylose content. Similar results by Foley et al. (2006) indicated that *in situ* starch degradability was greater for a standard barley variety compared to a waxy barley variety. Contrasting results from Stevnebø et al. (2009) suggested that low amylose barley varieties had greater rate of digestion than normal or high amylose varieties. Ultimately, there is some support to suggest that amylose and amylopectin content of cereal grains may alter digestibility, but further research may be necessary to better understand the relationship between amylose content and digestibility of cereal grains for ruminants.

2.1.4 Cereal Grain Processing and Digestibility

Due to the complexity of cereal grain structure, cereal grains are inherently resistant to ruminal degradation without mechanical processing. The development of a highly indigestible hull or seed coat makes the endosperm difficult to access for microbial digestion. As a result, processing of cereal grains increases digestibility by disrupting the fibrous seed coat and allowing access of microbes to the endosperm for enzymatic digestion (Mathison, 1996; Koenig et al., 2003). There are a number of processing methods developed for cereal grains, though the most common include dry-rolling, steam-flaking, temper-rolling, and grinding. For some grains, the method of processing has a large impact on the rate and extent of utilization. However, there is also a relatively large cost imposed by processing, thus it is imperative to choose the most cost-effective method of processing while also maximizing digestibility.

2.1.4.1 Dry-rolling

Dry-rolling grain is a process in which dry grain kernels are passed between two large grooved rollers causing the grain kernel to become fractured. The goal for dry-rolling is to increase microbial access to the endosperm of grain kernels by damaging the pericarp. The severity of processing can be manipulated based on the gap between the two rollers, with a narrower gap increasing the severity of processing. Moreover, the roller groove pattern can also affect the severity of processing. Uniformity of the rolled product is largely reliant on the uniformity of the kernels being processed, with batches that have high variation in kernel size resulting in greater variation in processing of individual kernels within a batch (Yang et al., 2013). Studies have demonstrated that for barley grain, adjusting roller gap settings to account for kernel size can increase the rate of *in situ* starch disappearance (Ahmad et al., 2010), as well as increase dry matter (**DM**) and nutrient intake and improve digestibility of CP and ADF (Yang et al., 2013).

In western Canada, dry-rolling is a very common method of processing barley grain due to its cost effectiveness. For barley grain, Mathison (1996) estimated that starch digestibility may be improved by up to 37% in dry-rolled compared to whole grain. Due to the rapidly degradable starch and protein present in barley grain, simple processing methods such as dry-rolling are effective at improving digestibility. However, it is also important to manage the severity of processing for barley grain in order to reduce risk of acidosis and digestive upsets. Differences in the starch structure between corn and barley grain have major effects on feed utilization and optimal processing. Due to the complex starch and protein matrix of corn grain and limited access for microbial digestion, dry-rolling is not considered to be an ideal processing method as it does not completely disrupt the protein matrix so as to expose starch granules to microbial digestion. In fact, the benefits of dry-rolling corn may be so small that energy content of dry-rolled corn may actually be lower than that of whole corn (Owens et al., 1997; Zinn et al., 2011). However, Zinn et al. (2011) estimated that feeding whole corn resulted in 2.5% less average daily gain (**ADG**) and increased dry matter intake (**DMI)** by 3.2% compared to dry-rolling.

For dry-rolled grains, severity of processing can be evaluated in a number of ways. Processing index (**PI**) is a measure of the bulk density (kg/L) of a grain after being processed relative to its original unprocessed bulk density and is expressed as a percentage. As processing severity increases, bulk density decreases, thus, cereal grains with a higher PI are less severely processed than those with a low PI. In addition to PI, the proportion of fines produced (particles which pass through a 1.18-mm sieve) during processing generally increases with processing severity. Since fine particles may increase risk of acidosis (Beauchemin et al., 2001), it is generally desirable to minimize the amount of fines produced during processing. In addition to PI, particle size of processed grains may be measured using a series of sieves with decreasing apertures to determine the mean size and uniformity of processed particles.

For barley grain, the recommended PI ranges from 70 to 80%, depending on the aggressiveness of the program and level of forage inclusion within the diet (McKinnon, 2015). Recommendations for dry-rolling corn grain broadly suggest that corn kernels should be coarsely processed to reduce production of fines, with kernels being fractured into 4 to 10 particles (Schwandt et al., 2017). A survey of 31 feedlots feeding dry-rolled corn in the US indicated an average particle size of 4.5 mm with values ranging from 2.2 to 6.8 mm, but authors suggested that processing severity could be increased in most cases (Schwandt et al., 2017). Engel et al. (2014) suggested that a mean particle size of 3.5 to 5.5 mm maintained DMI and improved the feed efficiency of finishing cattle. Though, a previous study by Secrist et al. (1995) indicated that to optimize feed efficiency and ADG, that an average particle size of 1.63 to 1.74 mm was optimal for corn grain. Dry processing of corn grain to a point adequate to improve digestibility may result in the excessive production of fines. As such, there is still considerable debate surrounding the optimal dry-rolling severity for corn grain, though most studies indicate that processing corn more severely than presently practiced in industry may improve performance.

2.1.4.2 Temper-rolling

Many feedlots in western Canada feed tempered barley grain which involves adding water to bring moisture up to 14 to 24%, allowing feed to absorb moisture for 8 to 24 h, and then rolling the grain (Yang et al., 1996). This processing method allows for more consistent processing as the kernels swell in size, improving the ability to regulate particle size of the processed kernel while rolling. Other benefits include reducing the production of fines which may allow for improved bunk management (Yang et al., 1996; Dehghan-banadaky et al., 2007). A study conducted by Bradshaw et al. (1996) reported improvements in whole tract DM digestibility, gross energy (**GE**) digestibility, and digestible energy (**DE**) content of 5.5, 5.7 and 6.9%, respectively, for tempered relative to dry-rolled barley. As such, if feeding rolled barley with low moisture levels, it may be cost effective to impose temper-rolling instead of dry-rolling, as a strategy to reduce fines and increase DMI. Contrarily, tempering of grains prior to rolling that already contain sufficient moisture (13%) to maintain kernel integrity may not be advantageous (Mathison et al., 1997). For tempered-rolled barley, Beauchemin et al. (2001) indicated an optimum PI of 75% for finishing cattle, but suggested that severity could potentially be increased to 65% for feedlot diets containing a larger proportion of effective fibre.

Though less common than for barley grain, tempering of corn grain before rolling may also be advantageous. Zinn et al. (1998) reported improvements in ADG, feed efficiency, and dietary NE of 9, 5, and 3% respectively for temper-rolled corn compared to dry-rolled corn. Zinn et al. (1998) also found that daily gain of cattle fed temper-rolled corn was similar to those fed steam-flaked corn, though noted no differences have been reported between dry-rolled and temper-rolled corn with regards to ruminal and total-tract digestion of organic matter (**OM**), nitrogen (**N**), and starch. In a previous study, Zinn (1988) found that tempering corn increased total-tract starch digestion by 6.5%, and DE by 5.2% when compared to dry-rolled corn. However, there is limited research available regarding the optimal PI for temper-rolled corn.

2.1.4.3 Grinding

Grinding of grains results in a floury end product, the coarseness of which is determined by screen size that the particles must pass through. Ground grain products are more commonly incorporated into diets that are higher in roughage content. Leonard et al. (1989) observed an increase in ADG and decrease in fecal starch when feeding ground corn versus whole corn to steers fed hay-based diets. In theory, increasing surface area of corn grain by grinding should increase nutrient digestibility though that is seldom the case. Zinn et al. (2011) indicated that while grinding may seem appealing, that it does very little to disrupt the endosperm matrix and starch granules of corn grain. As a result, even though extensively processed, digestibility is generally not improved. NASEM (2016) reports an extensive list of studies that demonstrate impaired forage digestibility when fed in combination with ground corn. Thus, coarse rolling is generally recommended over finer grinding of corn grain.

Due to the rapidly degradable starch of barley grain, it is generally not recommended to grind as there is an increased risk for bloat and acidosis due to greater fine particle production relative to dry-rolling. Additionally, grinding barley may produce a large amount of dust and may decrease feed intake. Mathison (1996) reported that finishing steers fed ground barley grew slower and had a poorer feed efficiency than those fed dry-rolled barley. Additionally, feed intake was 5% lower and backfat thickness was reduced, indicating that steers fed ground barley were less energetically efficient than those fed dry-rolled barley.

2.1.4.4 Steam-flaking

Steam-flaking utilizes moisture and heat to gelatinize starch granules and disrupt the intermolecular bonds between protein and starch. To steam-flake, the grain is passed through a steam chest at a specified temperature and maintained for a specified duration (20 min recommended for corn), then thinly rolled between corrugated rollers similar to those used for dry rolling while kernels are still hot. Of 24 nutritionists located throughout the United States surveyed by Samuelson et al. (2016), 70.8% reported that steam-flaking was the primary processing method used for corn grain at their consulting operations. Steam-flaking increases the starch availability of corn grain by up to 18% when compared to feeding whole corn (Zinn et al., 2002). Additionally, steam-flaking corn increases the rate and extent of ruminal starch digestion compared to whole corn (Therurer et al., 1996).

For barley grain, there may be opportunity to increase feed value through steam-flaking, though the magnitude of improvement in digestibility with steam-flaking is lesser than with corn and may not justify the cost difference compared to dry-rolling. The previous statement is based on variable results observed for cattle fed steam-flaked barley. Owens et al. (1997) conducted a review of cereal grain processing methods including 6 studies comparing steam-flaked barley and reported no improvement in ME content compared with dry-rolling. Several studies have reported an improvement in feed value for steam-rolled barley when compared to its dry-rolled counterpart (Zinn, 1993; Owens et al., 1997). For example, Zinn et al. (1996) found that ruminal and total-tract digestibility of starch was greater for barley when steam-flaked versus dry-rolled, noting that DE was increased by 3.5 to 3.7%, and reported that moderate flaking densities improved gain-to-feed (**G:F**). The variability in response to steam-flaking barley grain can likely be attributed to processing differences: a variable that is often not well described in studies. Additionally, the starch present in barley grain is readily degraded within the rumen when dry-rolled.

There are a number of parameters that can be used to assess the quality of steam-flaking achieved such as flake thickness (mm; average thickness of 10 random flakes), flake or bulk density (kg/L), starch solubility (amyloglucosidase-reactive starch), and enzyme reactivity (porcine-pancreatin-amylase reactive starch; Zinn et al., 2002). Of these standards, flake or bulk density is the most commonly used, but is not necessarily the most reliable as it can vary based on the amount of fines present in the sample, moisture loss, abrasion during handling, and freshness of flakes (Zinn et al., 2002). However, flake density can be rapidly determined and allows near immediate adjustments to be made and, though a less reliable indicator of starch digestibility, is closely associated with starch solubility and enzyme reactivity (Zinn et al., 2002). For corn grain, Zinn et al. (2002) recommend optimal flake densities of 0.31 kg/L, and suggested that although starch solubility may be increased when flaking to densities less than 0.31 kg/L, that DMI will be impaired and cattle may be predisposed to acidosis and bloat, causing variable weight gain. Current research evaluating steam-flaked barley has not evaluated an optimal flake density for barley grain, though studies have demonstrated an improvement in feeding value of steam-flaked barley relative to dry-rolled barley at flake densities of 0.39 and 0.19 kg/L (Zinn, 1993), and 0.26 kg/L (Zinn et al., 1996), but further research may be warranted to identify optimal steam-flaking conditions for barley grain.

2.1.5 High-Moisture Grain

High-moisture grain is achieved by harvesting grain at > 24% moisture content, followed by rolling and anaerobic fermentation. Zinn et al. (2011) reported that total-tract starch digestion was similar between high-moisture and steam-flaked corn, though ruminal digestion of starch was nearly 8% greater for high-moisture corn. As a result, the NE_m and NE_g content of high-moisture grain was slightly lower than dry-processed corn, but was improved by nearly 6% when grinding or rolling corn before ensiling (Zinn et al., 2011). The high-moisture content or rapid starch availability of high-moisture-corn grain may reduce DMI, though Owens et al. (1997) reported that ADG was not affected, and feed efficiency and ME were improved. Although fairly common to harvest high-moisture corn grain, barley is less typically harvested as a high-moisture feed and recent studies are limited. That said, Kennelly et al. (1988) observed that while high-moisture barley reduced ADG, overall results indicated that, on a DM basis, high-moisture barley had a similar feeding value to dry-rolled barley. Similar to corn, digestion of high-moisture barley may be improved by rolling prior to ensiling (Rode et al., 1986).

2.1.6 Corn Type and Processing Requirements

Flint corn varieties contain an endosperm that is more vitreous than dent varieties, which results in less degradable starch and protein as they are entwined in a complex matrix that is highly resistant to degradation. As a result, there are considerations for the processing requirements of corn grain based on the type of starch present. Philippeau et al. (1998) demonstrated that *in situ* ruminal starch degradation was 13% greater for dent than for flint corn. Similarly, Jaeger et al. (2006) indicated that steers fed corn with a greater proportion of soft endosperm were more efficient than steers fed corn containing hard endosperm. In a study conducted by Macken et al. (2003), when dry-rolled, corn hybrids with a floury endosperm were utilized more efficiently than corn hybrids with a flinty endosperm. However, when the same types were fed as high-moisture corn, there were no differences in G:F observed. Corona et al. (2006) found that differences between dent and flint varieties observed when processed by dry-rolling were eliminated when steam-flaked. Results of these studies indicate that digestibility of flint corn varieties which contain a greater proportion of vitreous starch may benefit from more extensive processing methods than dry-rolling, such as steam-flaking or harvest as high-moisture corn. Thus, producers opting to utilize dry-rolling may also benefit from selecting hybrids which contain a greater proportion of floury endosperm in order to maximize digestibility.

2.1.7 Grain Source and Finishing Cattle Performance

Western Canadian finishing cattle diets may be composed of up to 90% cereal grains, the most common being barley grain due to its availability and cost. However, corn grain use is increasing on the prairies due in part to increased acreage of hybrid corn varieties, but also due to increasing costs of barley grain and relatively low cost of corn. One of the significant advantages of utilizing barley grain is its relatively high CP content (~12.4%) compared to corn grain (~8.8%). Given that most finishing diets are formulated to achieve 12.5 to 14.4% CP (Galyean, 1996; Samuelson et al., 2016), many producers in western Canada may not need an additional protein source to achieve this level, while corn-based diets incur additional costs associated with protein supplementation.

When comparing corn and barley grain, corn grain has generally been considered a superior feed source due to its greater energy content. Barley grain contains greater fibre and less starch than corn grain. For dry-rolled corn grain, NASEM (2016) assigns a greater TDN, DE, ME and NE value than for barley. Lower energy values for barley grain should result in poorer performance relative to corn fed diets, though results have been variable. Despite the theoretical energy difference between dry-rolled corn and barley grain, a number of studies have reported no difference in ADG or feed efficiency for cattle fed dry-rolled corn or barley (Mathison and Engstrom, 1995; Milner et al., 1995; Koenig and Beauchemin, 2005), while some have reported that dry-rolled barley fed cattle actually performed better than their dry-rolled corn fed counterparts (Beauchemin et al., 1997), and others have found that dry-rolled barley fed steers performed worse (Boss and Bowman, 1996a; McEwen et al., 2007).

A study conducted by Koenig and Beauchemin (2005) found that when feeding diets composed of either steam-rolled barley or dry-rolled corn supplemented with urea or canola meal to deliver at least 13% CP and similar level of degradable intake protein (**DIP**) to barley diets, that cattle had similar performance. However, when feeding the dry-rolled corn diet without protein supplementation (10% CP) ADG was 10% lower and DMI was 8% lower than the barley-based diet. Contrarily, in a second, separate study, Beauchemin and Koenig (2005) found conflicting results in that cattle fed diets composed of either steam-rolled barley (13.8% CP) or dry-rolled corn (9.2% CP) had similar overall gains and greater efficiency, while those that had a portion of corn (7 or 23% of DM) replaced with corn gluten feed had decreased performance. Authors suggested that corn-based diets containing about 9.5% CP and at least 50% DIP may be sufficient to achieve similar performance to cattle fed barley-based diets, but supplementing with corn gluten feed reduced dietary digestible energy enough to impair performance. Milner et al., (1995) reported that steers fed coarsely cracked barley and corn did not have any differences in ADG, although carcass weight was greater for corn fed steers. In another study, Kincheloe et al. (2003) reported that steers fed dry-rolled barley had similar ADG, feed efficiency, DMI, and starch digestibility as steers fed dry-rolled corn. As such, there is a body of evidence to support that performance may be similar for cattle fed corn or barley grain (Milner et al., 1995; Kincheloe et al., 2003; Koenig and Beauchemin, 2005).

For studies reporting improved performance for barley fed cattle, Beauchemin et al. (1997) found that steers fed steam-rolled barley grew faster, had increased DMI, and were more efficient than steers fed steam-rolled corn. In the same study, authors found that barley fed steers also had improved carcass marbling (brighter color and more abundant) compared to corn. Boss and Bowman (1996a) found mixed results in that feed efficiency for three barley varieties tested were greater than for corn, though carcass weight and ADG were greater for corn fed steers. In a companion study, Boss and Bowman (1996b) demonstrated that total-tract digestion of starch was greater for barley than for corn, and that corn fed steers had lower microbial N flow and microbial efficiency, indicating that differences in the digestive characteristics between grains may explain differences in performance. Another study conducted by McEwen et al. (2007), demonstrated that Angus cattle fed cracked corn had greater gains and DMI than those fed rolled barley, while Charolais cattle fed rolled barley had lower DMI and greater efficiency, with no effect on gain.

Overall, the results regarding performance of cattle fed corn and barley grain have been largely inconsistent, the variability may be partially due to differences in processing methods of grains between studies. Beauchemin et al. (2001) recommended an optimal processing index for dry-rolled barley grain of 75% or lower for finishing cattle, and that more coarsely rolled grains resulted in lowered digestibility and microbial N synthesis. In another study, Koenig and Beauchemin (2011) reported that although less severe processing of barley grain reduced risk of acidosis, feed efficiency was also impaired, a finding supported by Mathison et al. (1997). A review paper by Owens et al. (1997) suggested that ME content of barley grain was greatest when dry-rolled, intermediate for steam-rolled, and least when fed whole. Zinn (1993) indicated that the comparative feeding value of dry-rolled barley, coarsely steam-rolled barley, and thinly steam-rolled barley were 90, 92, and 96% the value of steam-flaked corn, respectively. For corn grain, a review paper by Owens et al. (1997) determined that ME values of corn were greatest when steam-rolled, intermediate for whole or high-moisture, and least when dry-rolled. These results are consistent with those reported in a more recent review of corn processing by Zinn et al. (2011) in which NE_m values were greatly increased for steam-flaked corn, and lower, but similar for dry processed and whole corn.

Another potential factor contributing to the variability in results regarding the feeding value of barley compared to corn may be barley variety. Studies evaluating barley varieties have demonstrated up to 15% greater ADG (Milner et al., 1995) and up to 8% greater ADF digestibility

(Bradshaw et al., 1996) between varieties. Boss and Bowman (1996a) evaluated Gunhilde, Harrington, and Medallion barley varieties and determined that Harrington resulted in 8% faster gains, greater carcass weight, and improved carcass quality compared to the other two barley varieties. Results of these studies indicate that barley variety could potentially have large effects on performance and varieties should be selected for varieties demonstrating improved digestibility by feedlot operators who produce their own feed. These performance results also suggest that values reported by NASEM (2016) are underestimating the energy value of dry-rolled barley grain (Owens et al., 1997). When calculated based on animal performance, ME values have been reported to be significantly greater than indicated in tables, and in some cases are greater or similar to corn grain (Owens et al., 1997; Kincheloe et al., 2003). Additionally, NASEM (2016) may be overestimating the energy content of dry-rolled corn (Zinn et al., 2002).

2.2 Cereal Silages

2.2.1 Yield Potential of Corn and Barley Silage

Cereal silage crops produced in western Canada include corn, barley, wheat, oat, and triticale, with legume silages including alfalfa, faba bean, and field pea. While a number of these crops are more commonly fed to dairy or backgrounding cattle, corn, barley, and wheat are the most common silage crops fed to finishing cattle.

Growth of corn for silage production in western Canada has increased in recent years and in some areas is replacing the use of barley silage. Several factors have contributed to the growth of the corn industry in western Canada, most importantly is the development of short-season hybrid corn varieties that require fewer CHU to reach maturity. Additionally, an increase in accumulation of CHU and precipitation on the Prairies (Nadler and Bullock, 2011), when combined with these new varieties, has reduced some of the risk associated with growing corn. The main factors dictating silage variety selected by producers include risk, cost of production, yield potential, and nutritive value. However, risk still does exist in that shortened growing seasons may result in corn not achieving optimal DM for silage production or yield potential (Baron et al., 2014).

Though corn silage has nearly twice the cost of production of barley silage, it also has a much greater yield potential than barley silage under favorable growing conditions (Baron et al., 2014). There are currently few studies reporting recent yields for short-season corn varieties in western Canada. Baron et al. (2014) reported that in a 5-yr swath grazing study, corn yielded 32%

more DM than barley at an average DM yield of 13.5 t/ha for corn compared 10.2 t/ha for barley. In the same study, corn also had a 51.3% greater carrying capacity and feed costs were lowered by \$0.19/cow/d. Lardner et al. (2017) reported similar results in a 3-yr, 4-location study evaluating yields of three low heat unit corn varieties compared to barley. Yield among corn varieties was similar, but were 40% greater than barley with a DM yield of 11.4 t/ha for corn and 6.7 t/ha for barley. In a more recent study, Guyader et al. (2018) evaluated six corn hybrids over 3 years in 4 locations. Yields varied from 9.5 to 19.2 t/ha between locations and years, with considerable variability between varieties and years. However, it is worth noting that CHU accumulated and precipitation received also varied greatly. Ultimately, results consistently indicate that DM yield of corn is greater than that of barley when growing conditions are optimal.

2.2.2 Chemical Composition of Corn and Barley Silage

Given the greater yield potential and cost of production for corn silage, it may be a cost-effective alternative to barley silage if nutrient composition is similar. Feed reports from CVAS (2019) indicate that corn silage from both western Canada and the Upper Midwest US contain greater starch, TDN, NE_m, and NE_g than barley silage (Table 2.2). However, barley silage has a greater CP, ADF, NDF, and fat content and has historically been better suited for silage production in western Canada. As a grain source, corn contains more fat than barley but when harvested as whole plant silage, barley silage typically contains greater fat content.

However, there are some discrepancies between values reported for barley silage by NASEM (2016) and those reported by CVAS (2019) and observed in actual western Canadian studies. For example, NASEM (2016) reports values of 9.17% starch and 60.6% TDN for barley silage. Regarding starch values for each forage observed in western Canadian studies, Chibisa and Beauchemin (2018) reported starch concentrations of 24.2% for barley and 28.2% for corn. In another study, Addah et al. (2011) reported starch content of barley silage to be 23.29% and 32.38% for corn silage. In a study conducted by Nair et al. (2016) evaluating seven common barley forage varieties, starch content ranged from 14.7 to 24.7%, the lower of which is still greater than values reported by NASEM (2016). In the same study, TDN for barley silage varieties was also reported to range from 63.6 to 67.4%, these values indicate that NASEM (2016) may be greatly underestimating the starch content and consequently the energy content of western Canadian barley silage. Additionally, discrepancies between values reported for corn and barley silage

Table 2.2 Nutrient composition (mean ± SD) of Canadian barley and corn silage and Upper Midwest US corn silage as reported by Cumberland Valley Analytical Services (2019)[1].

	Western Canada[2]		Upper Midwest US[3]
	Barley silage	Corn silage	Corn silage
OM, % DM	92.9 ± 1.88	95.7 ± 1.30	96.4 ± 0.95
CP, % DM	11.6 ± 2.1	8.6 ± 1.32	7.7 ± 0.99
Starch, % DM	17.9 ± 7.58	25.3 ± 8.39	33.1 ± 6.04
ADF, % DM	29.2 ± 5.20	26.7 ± 4.30	24.2 ± 3.15
NDF, % DM	48.4 ± 6.06	45.7 ± 6.56	40.1 ± 4.78
Fat, % DM	3.1 ± 0.66	2.8 ± 0.46	3.0 ± 0.37
TDN, % DM	65.0 ± 4.1	69.6 ± 3.5	72.2 ± 2.56
NE_m, Mcal/kg	1.48 ± 0.13	1.61 ± 0.11	1.70 ± 0.09
NE_g, Mcal/kg	0.88 ± 0.13	1.01 ± 0.11	1.08 ± 0.07

[1]Values reported from January 1, 2014 to January 1, 2019.
[2]For Canadian barley silage n ≥ 7,536; for corn silage n ≥ 7,123.
[3]For Upper Midwest US corn silage n ≥ 46,527.

between studies referenced previously and those reported by NASEM (2016) may be due to differences in variety and geographically different growing conditions. Samples for values reported by NASEM (2016) are collected from 3 analytical labs located in the United States (DairyOne, Ithaca, NY; Servi-Tech Laboratories, Hastings, NE; and Ward Laboratories, Kearney, NE), and may not represent the quality of silage produced in western Canada as accurately as those from CVAS (2019).

2.2.3 The Ensiling Process

Ensiling of feed allows preservation of high-quality forages with a high nutrient content for feeding at a later date. Compared to hay, silage offers increased yield and quality of nutrients as well as decreased harvest costs and losses (Jones et al., 2004). However, high quality silage production requires intensive management of harvest, storage, and feed-out phases with more loss and at a higher cost than for dry-preserved feeds. Poor management at any of these critical stages can result in enormous losses of DM and feed quality (Borreani et al., 2018). Quality of silage produced is controlled primarily by the quality of fermentation achieved, which is dictated by: 1) forage moisture content, 2) chop length, 3) exclusion of air, 4) forage nutrient composition, and 5) bacterial populations.

2.2.3.1 Forage Dry Matter

The recommended DM concentration at the time of silage harvest is dependent upon the method in which silage will be subsequently packed and stored. For storage systems where forage can be more easily compacted, adequate packing to exclude oxygen can be achieved at higher DM levels. As DM increases, packing becomes more difficult. Contrarily, harvesting silage when too wet (< 28% DM) can also compromise silage quality increasing nutrient leaching and runoff, and result in unfavourable fermentation.

Dry matter of forages is largely associated with maturity. As maturity (and DM) increases, CP, NDF and NE levels decrease, while level of starch increases. Although greater starch content would appear to be desirable, overall digestibility of nutrients decreases with maturity. It is usually recommended that barley be harvested for silage at the mid- to late-dough stage with DM ranging from 60 to 70%. For corn silage, a DM of 65 to 70% is recommended for silos and bunkers, while a broader range of 60 to 70% is acceptable for storage in bags (Jones et al., 2004). In the US, the grain kernel milk line can be used as an indicator of DM content and maturity. Starch digestibility of corn silage is maximized when harvested at 1/2 to 2/3rd milk line of the corn kernel (Harrison et al., 1996). If allowed to reach the black line stage, where starch has completely filled the corn kernel, digestibility of both fibre and starch will be impaired. However, the milk line is a poor indicator of maturity and DM in western Canadian hybrid varieties, and DM content should be monitored instead by frequent collection of representative samples of corn stalks (5/row in two locations of the field; Beauchemin et al., 2018).

2.2.3.2 Chop Length

Just as DM influences silage quality and fermentation, particle size of forages at harvest is equally important, and also has a large potential to affect not only silage packing and storage quality, but also DMI and digestibility when fed (Soita et al., 2002; Addah et al., 2014). In finishing diets, forage is included to provide a source of physically effective fibre (**peNDF**) that contributes to the development of a fibrous rumen mat and minimizes digestive upsets by stimulating rumen motility and rumination. Increasing the theoretical chop length (**TCL**) of forages increases intake of peNDF, but in diets containing a high amount of forage it may restrict DMI by reducing digestibility (Ferraretto et al., 2018) or increasing sorting of the diet.

Results of forage TCL on nutrient digestibility have been inconsistent (Ferraretto et al., 2018). Barley silage harvested with TCL of 10 or 20 mm resulted in no differences in performance of feedlot cattle fed diets containing silage at 10% of DM (Addah et al., 2014). A study conducted by Soita et al. (2002) demonstrated that for steers fed an all silage diet, barley silage harvested with a TCL of 4.7 mm had improved digestibility compared to the same forage harvested with a TCL of 18.8 mm. Though silage harvested with TCL < 10 mm may result in increased passage rates which could potentially decrease overall nutrient digestibility, increased surface area for bacterial digestion may counteract this potential decline (Johnson et al., 1999). Contrarily, longer forage chop lengths may result in a longer ruminal retention, potentially increasing the extent of NDF digestibility. Nevertheless, recommendations for barley silage and corn silage (harvested without a kernel processor) chop length are ~10 to 12 mm while corn silage harvested with a kernel processor (discussed below) can be chopped more coarsely at ~19 mm (Beauchemin et al., 2018). The difference in the theoretical chop length with and without kernel processing is related to the need to chop more finely to ensure adequate starch digestibility when harvested without a kernel processor.

While some mixers have the ability to reduce forage particle length, it is critical to monitor forage particle size during harvest to ensure forages are being chopped consistently to the desired length. Particle size distribution can be determined using a Penn State Particle Separator fit with three screens containing aperture sizes of 19, 8, and 4 mm on the top, middle, and bottom screens, respectively. There are no definitive guidelines for particle size distribution of barley silage; available recommendations for corn suggest that 3 to 8% of the forage sample weight be retained on the top screen, 45 to 65% on the middle screen, and 20 to 30% on the lower screen, with the bottom pan collecting < 10%.

2.2.3.3 Kernel Processing

Harvesting corn silage while subsequently processing kernels with two counter-rotating rolls is a relatively recent advancement in silage production in North America (Ferraretto et al., 2018). The use of a kernel processor acts similarly to dry grain processing by exposing the endosperm of the grain kernels to improve starch digestibility. Similarly, the severity of kernel processing achieved is controlled by the gap between the rollers, with a narrower gap inflicting more severe processing. In a meta-analysis, Ferraretto and Shaver (2012) reported that total-tract starch digestibility was increased on average by 5.9% when processed with a 1 to 3 mm gap setting and by 2.8% when processed with a 4 to 8 mm gap relative to unprocessed corn silage. Weiss and Wyatt (2000) reported that for dairy cattle, kernel processing increased milk fat percent, starch digestibility, and TDN compared to non-processed corn silage. Similar results were reported by Shinners et al. (2000) in that processing corn silage increased fat corrected milk yield and increased *in situ* DM disappearance. Johnson et al. (2002) reported conflicting results of kernel processing on energy content of corn in two experiments. In experiment 1, processed corn had lower TDN and net energy of lactation (**NE_L**), and lower total-tract digestibility of NDF, fat, and CP. In experiment 2; however, TDN and NE_L were greater in processed corn silage as well as greater total-tract digestibility of starch and NDF were observed.

Use of a kernel processor allows longer TCL while still achieving high starch digestibility of the corn grain kernels. Previously, mechanical damage to kernels was achieved by utilizing short TCL settings. Shinners et al. (2000) reported that at a chop length of 18 mm, addition of a kernel processor increased the amount of kernels fractured from 51% to > 90%. However, benefits of utilizing a kernel processor are greatest for silage DM ranging from 32 to 40%, with increased virtuousness of kernels in corn silage containing a DM > 40% resulting in poor fracturing of the kernels (Ferraretto and Shaver, 2012). Due to the fact that short-season corn hybrids are a combination of dent and flint varieties, kernels are likely more vitreous and rumen availability of starch can be greatly improved by use of a kernel processor (Miorin et al., 2018). Additionally, use of a kernel processor may increase the availability of substrates for fermentation and may aid in achieving a rapid and complete fermentation during ensiling (Johnson et al., 2003).

2.2.3.4 Filling and Packing

Filling and packing of the silo or bunker should occur as quickly as possible such that DM losses due to plant respiration are minimized. Rapid harvest and filling help to ensure that the majority of the crop remains at the target moisture content and maturity and limits aerobic respiration. Respiration may occur as long as oxygen and readily available plant carbohydrates are available, thus rapid packing will not only reduce the duration of aerobic respiration, but will also increase nutrient preservation. The presence of air pockets within the silage pile will increase spoilage due to heat caused by aerobic respiration. As density of the silage pack increases, oxygen is excluded. However, the level of silage density achieved depends largely on crop variety, moisture content, chop length and silo type. For horizontal silos, a bunk density of approximately 640 kg/m^3 or greater is recommended while a value of 705 kg/m^3 or greater is recommended for bunker or pile silos (Jones et al., 2004; Borreani et al., 2018). Generally speaking, as DM density increases, DM losses will decrease (Borreani et al., 2018), thus it is imperative to compact silage as densely as possible to reduce losses. High density silage packing can be achieved by spreading forage layers as thinly as possible, increasing packing equipment weight, increasing time spent packing, and increasing the height of the silage pile (Borreani et al., 2018).

In addition to rapid packing and filling of the silage pit, covering of the pit should occur rapidly once adequate density has been achieved. Leaving silage piles uncovered can result in considerable DM losses (Borreani et al., 2018). Care should be taken to ensure that a barrier with low oxygen permeability is selected and adequately secured to the pit to exclude oxygen. Plastic used to cover silage pits should overlap by 1.2 meters at joints and around the edges to create an effective seal (Bolsen, 2006).

2.2.3.5 Phases of Fermentation

After packing, fermentation is commonly classified into 4 phases: 1) aerobic fermentation and respiration; 2) anaerobic fermentation; 3) the stable storage phase; and 4) the feed-out phase. Before active fermentation can occur in a covered pit, aerobic respiration utilizes the oxygen present. Though this phase can occur over hours, it is important to minimize its duration as the plants and microbes consume water soluble carbohydrates (**WSC**) such as sugar in combination with oxygen to produce carbon dioxide, water, and heat (Jones et al., 2004). Consumption of WSC prior to the anaerobic respiration phase is undesirable as it reduces available substrates for fermentation. Heat production is a normal occurrence in early stages of silage production, but a prolonged aerobic phase can cause poor quality silage by denaturation of proteins (Borreani et al., 2018).

As oxygen is consumed, the silage pile shifts to the anaerobic phase of fermentation, with a transient increase in acetic acid production. Acetic acid production causes a rapid decline in pH, the extent to which actually depletes the number of acetic acid bacteria (Jones et al., 2004), and promotes growth of lactic acid bacteria (**LAB**). The LAB ferment plant carbohydrates (primarily WSC) into lactic acid. Dry matter losses are somewhat inevitable outcomes of fermentation, but the magnitude of loss as CO_2 are largely dependent upon the types of bacterial species present. Certain homofermentative LAB are the most efficient at lactate production, producing 2 lactate per glucose fermented, with no loss of energy in the form of other end-products (Borreani et al., 2018). However, if organisms other than LAB play a significant role in fermentation, energetic losses can be substantial. Since WSC are one of the primary substrates consumed during fermentation, levels in forages during harvest are an important consideration. At optimum maturity for harvest, barley forage contains relatively high levels of WSC at 10 to 20%, while corn forage contains much lower levels at around 3 to 10% (McAllister et al., 1995; Johnson et al., 2003; Hargreaves et al., 2009). Since the type of fermentation that occurs in an enclosed silage pit is largely uncontrolled, the use of additives during the ensiling process may improve the level of fermentation and quality of silage produced. As LAB populations peak, lactic acid production continues until about 21 days after ensiling, at which point the pH is low enough to limit bacterial growth. During this stage, commonly referred to as the storage phase, forage can be stored for extended periods if adequate fermentation was achieved. The rate and extent of pH drop and type of acid driving the pH change are considered key indicator of an optimal fermentation that will result in quality silage. Assuming that the pit has been adequately covered, DM losses during the storage phase are low, though silages with low DM may have a small amount of effluent losses (Borreani et al., 2018).

The final phase of silage fermentation occurs during feed out of the silage. Exposure of the silage to oxygen can cause considerable aerobic deterioration of even the highest quality silage if the silage face is not managed properly. Penetration of oxygen within the silage face causes rapid growth of yeasts which consume sugar and fermentation acids, causing a rapid increase in silage temperature and pH (Pahlow et al., 2003). There are dramatic DM losses associated with spoilage and mold development of open silage faces. Special care should be taken to ensure that plastic covering the silage pile remains secure to the forage, and that as much of a barrier is maintained as possible. Maintaining a flat silage face will reduce oxygen penetration into the silage pile, minimizing risk for wide-spread spoilage. Though recommended feed out rates vary, the size of the silage face and number of animals being fed should be considered such that an adequate amount of feed can be removed daily so that spoilage of the silage face does not occur. The use of some silage additives may also aid in maintaining forage quality during the feedout phase by inhibiting growth of yeasts and molds.

2.2.3.6 Silage Additives

There is an enormous body of research focused on the use and efficacy of silage additives. Additives can be broadly classified as stimulants of fermentation (inoculants), nutrient additives (fermentable substrates), or fermentation inhibitors. In some cases, the use of additives have also been shown to improve milk production, daily gain, and even feed efficiency, though results are variable and in many cases difficult to explain (Weinberg and Muck, 1996). Silage inoculants that supply rapidly growing homofermentative LAB have been developed to quickly decrease silage pH and have been demonstrated to decrease DM losses, presumably through reduction in fermentation related losses (Kung et al., 1998). When WSC levels are predicted to be insufficient, the use of nutrient additives to supplement the forage with additional fermentable substrates may be necessary to achieve a rapid drop in pH. Fermentation inhibitors such as salts and organic acids can be useful when crops are harvested at low DMs and are at risk for development of clostridial fermentation (Muck et al., 2018).

Though research is ongoing, additives also have a positive effect on aerobic stability during the feedout phase (Muck et al., 2018). Major improvements in silage additive technology has improved their efficacy, but the efficiency of fermentation achieved is still largely dependent upon the interactions between the forages naturally occurring bacterial populations and those supplied by the additive, as well as the chemical composition of the forage (Muck et al., 2018). Though barley typically contains higher WSC at harvest than corn, corn often has greater populations of naturally occurring LAB. Thus, the choice to use silage additives at the time of harvest should be based on harvest conditions and cost-benefits associated with potential improvement in silage quality.

2.2.4 Differences in Digestibility between Corn and Barley Silage

The digestibility of silage can be largely affected by maturity at harvest, chop length, use of a kernel processor at harvest, and cultivar. Improvements in digestibility that can be achieved by harvesting at optimal maturity, selecting the ideal chop length based on forage variety, and kernel processing at harvest have already been discussed. There are surprisingly few studies directly comparing digestibility of corn and barley silage, likely due to the limited overlap in geographical growing areas. Due to the importance of silage in dairy cattle diets, there are more comparisons available with relevance to dairy production than beef cattle. For example, Refat et al. (2017) reported that corn silage had greater *in vitro* DM digestibility compared to barley silage and resulted in greater milk yield for corn silage fed cows. Benchaar et al. (2014) reported that DMI, milk production, and DM digestibility increased with increasing corn silage inclusion for lactating dairy cows. In studies using beef cattle, Beauchemin and McGinn (2005) reported similar digestibility of most nutrients for backgrounding cattle fed diets containing either barley silage with barley grain or corn silage with corn grain. However, CP digestibility was greater for barley silage based diets. Walsh et al. (2008) reported that starch digestibility for corn silage was greater than for barley silage. Results of the above-mentioned studies suggest that corn silage typically has greater digestibility than barley silage, though more research on the differences in corn and barley silage for finishing diets may be warranted.

2.2.5 Silage Source and Growing Cattle Performance

In forage-based backgrounding diets, Chibisa and Beauchemin (2018) found that when feeding diets containing 60, 75, or 90% corn silage compared to 60% barley silage, DMI and ADG were greatest for barley silage diets and decreased with increasing corn silage. However, source or level of silage inclusion had no effect on carcass quality. Walsh et al. (2008) reported that feed efficiency was greater for steers fed corn silage than those fed barley silage during backgrounding. Beauchemin and McGinn (2005) reported that cattle fed corn silage and corn grain diets had greater DMI and ADG compared to cattle fed barley silage and barley grain diets. Oltjen and Bolsen (1980) reported that in two of three experiments, corn and barley silage fed steers had similar performance. In the third experiment, corn silage fed steers gained the most rapidly, but efficiency was similar between steers fed corn and barley silages. Bolsen et al. (1976) ultimately reported that steers fed corn and barley silage had similar feedlot growth performance.

The variation in performance of cattle fed either corn silage or barley silage may be due to differences in forage harvesting methods or forage varieties. Though there are a large number of studies that evaluate performance of feedlot cattle on finishing diets containing corn or barley silage as individual silage sources, there are no studies that have focused on comparing the effects between silage sources (corn vs. barley) and grain sources on the finishing performance of cattle fed high grain diets. Currently, information is lacking on the nutritive value and subsequent performance of finishing cattle fed either corn or barley silage.

2.3 Summary

In western Canada, barley grain and barley silage have historically comprised the majority of diets used for finishing beef cattle. However, there is increasing acreage of corn throughout the prairies due to the recent development of short-season corn hybrids that are suitable to the CHU accumulated in cooler western Canadian climates. Additionally, increases in feed prices have increased the interest in use of corn grain for finishing diets, when cost effective. However, differences in production and chemical composition should be considered when substituting corn for barley as silage or grain sources for finishing diets.

As cereal grains differ in kernel structure, differences in the nature and severity of processing are required to optimize digestibility. For barley grain, dry-rolling is sufficient for adequate starch digestibility. On the other hand, corn grain contains a complex starch and protein matrix that is resistant to ruminal degradation and as a result processing by steam-flaking is the most effective method of improving starch digestibility. However, access to steam-flaking infrastructure in western Canada is limited. Though greater energy of corn grain should translate to improved growth performance of feedlot cattle, studies indicate that the energy value of barley grain has been underestimated. Additionally, the greater CP content of barley grain must be considered as the cost of equivalent protein supplementation for corn grain may make it less economical. Producers considering the use of corn grain should consider the current processing methods used and potential impacts it may have on performance, or the potential cost of implementation of processing technologies such as steam flakers to maximize digestibility and performance of cattle fed corn grain.

Corn offers substantial potential yield benefits as a silage crop when growing conditions allow. Depending on the silage structure, there are differences in chop length and moisture level at harvest to consider between corn and barley silage as a result of differences in whole plant structure. Corn silage should be harvested with a kernel processor to maximize starch digestibility. Depending on harvest conditions, the use of silage additives may improve the rate and extent of fermentation achieved and increase overall silage quality. Studies indicate that digestibility of corn silage may be greater than that of barley silage, but variety, crop year, and harvest processing may have a large influence on nutrient digestibility.

Ultimately, there is potential to increase silage yield and cattle performance through adoption of corn production in western Canada. However, research regarding influence of silage source on finishing cattle performance is currently limiting. Producer selection of silage and grain source should consider differences in processing and production practices required to maximize digestibility and performance of cattle and ease of implementation on their operation.

2.4 Hypothesis

The hypotheses of the current studies were that due to the differing rates of starch and protein degradability for corn and barley grains, diets containing a mixture of grains, irrespective of silage source, will result in optimized starch and protein degradation and improve ruminal fermentation. As such, we expect to see improved growth performance for diets containing a mixture of both corn and barley grains.

2.5 Objectives

The current studies will evaluate the effects and interactions of silage type (corn vs. barley) and cereal grain type (corn vs. barley vs. blend) on DMI, ruminal fermentation, growth performance, carcass quality, total-tract digestibility, fecal pH, and microbial protein supply for finishing beef cattle.

3.0 USE OF BARLEY OR CORN SILAGE WHEN FED WITH BARLEY, CORN, OR A BLEND OF BARLEY AND CORN GRAIN ON GROWTH PERFORMANCE, NUTRIENT UTILIZATION, AND CARCASS CHARACTERISTICS OF FINISHING BEEF CATTLE

3.1 Abstract

The objective of this study was to evaluate the effects of silage source, cereal grain source, and their interaction on growth performance, digestibility, and carcass characteristics of finishing beef cattle. Steers weighing 464 ± 1.7 kg were assigned to 1 of 24 pens (12 steers/pen) in an 89-d finishing study. Diets were arranged in a 2 × 3 factorial with corn silage (**CS**) or barley silage (**BS**) included at 8% of DM. Within each silage source, diets contained dry-rolled barley (**BG**; 86% of DM), dry-rolled corn (**CG**; 85% of DM), or an equal blend of barley and corn grain (**BCG**; 85% of DM). Total-tract digestibility of nutrients was estimated from fecal samples using near infrared spectroscopy. Data were analyzed using the Mixed Model of SAS with the fixed effects of silage, grain, and the 2-way interaction. Carcass and fecal kernel data were analyzed using GLIMMIX utilizing the same model. There were no interactions detected between silage and grain source. Feeding CG increased ($P < 0.01$) dry matter intake by 0.8 and 0.6 kg/d relative to BG and BCG, respectively. Gain-to-feed was greater ($P = 0.04$) for BG (0.172 kg/kg) than CG (0.162 kg/kg), but did not differ from BCG (0.165 kg/kg). Furthermore, average daily gain (2.07 kg/d) and final body weight did not differ among treatments ($P > 0.05$). Hot carcass weight was 6.2 kg greater (372.2 vs. 366.0 kg; $P < 0.01$) and dressing percent was 0.57 percentage units greater (59.53 vs. 58.96 %; $P = 0.04$) for steers fed CS than BS, respectively. There was no effect of dietary treatment on the severity of liver abscesses ($P > 0.05$) with 72.0% of carcasses free of liver abscesses, 24.4% with minor liver abscesses, and 3.6% with severe liver abscesses. Digestibility of DM, OM, CP, NDF, and starch were higher for BG ($P < 0.01$) than CG or BCG. As expected, grain source affected appearance of grain kernels in the feces ($P \leq 0.04$). Feeding CS silage increased appearance of fractured corn kernels ($P = 0.04$), while feeding BS increased fibre appearance in the feces ($P = 0.02$). Results indicate that when dry-rolled, feeding BG resulted in improved performance and digestibility compared to CG and BCG. Even at low inclusion levels (8% of DM), CS resulted in improved carcass characteristics relative to BS.

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3.2 Introduction

Western Canadian feedlots have predominantly relied on the use of barley silage and barley grain as feed ingredients for finishing diets. However, the recent development of short-season corn hybrids offer a yield advantage as a silage sourcefor producers relative to barley silage (Lardner et al., 2017; Baron et al., 2014). Although corn silage typically has greater starch and lesser protein content than barley silage, the amount of dietary energy contributed by silage is relatively small in finishing diets. At such low levels of forage inclusion (< 10% DM basis) in finishing diets is more likely to provide value as a source of effective fibre rather than as a source of energy.

When processed similarly, starch and protein from barley grain is degraded more rapidly and to a greater extent in the rumen than corn grain (Herrera-Saldana et al., 1990). Due to the rapid fermentation of dry-rolled barley grain, the risk of ruminal acidosis is perceived to be greater than with dry-rolled corn, a response that can have a negative impact on average daily gain (**ADG**) and gain-to-feed (**G:F**) (Castillo-Lopez et al., 2014). Several studies have demonstrated that combining grain sources with differing rates of degradable carbohydrate fractions may improve efficiency and growth performance of finishing cattle (Kreikemeier et al., 1987; Stock et al., 1987b). That being said, there are currently no studies that compare barley and corn and limited studies that have evaluated short-season corn silage. Additionally, while previous studies have evaluated the use of either barley- or corn-based diets for finishing cattle (Beauchemin et al., 1997), they have not examined the interactions between cereal silage and cereal grain sources.

We hypothesized that that due to the differing concentrations of starch and the expected differences for starch and protein degradability in corn and barley grain, diets containing blended grains will result in improved digestibility, growth performance, and feed efficiency compared to single grain diets, with little effect of silage source.

3.3 Materials and Methods

Use of steers and the procedures used were pre-approved by the University of Saskatchewan Animal Research Ethics Board (protocol 20100021) according to the guidelines of the Canadian Council on Animal Care (Ottawa, ON, Canada).

3.3.1 Silage Production and Cereal Grain Processing

Corn (P7213R, 2050 CHU, DuPont Pioneer, Mississauga, ON) was seeded for silage at a rate of 79,072 plants/ha on May 27, 2016 with 76.2 cm row spacing. Anhydrous ammonia was applied to deliver 72.1 kg of N/ha and 4.03 MT of fertilizer was applied containing 36.3% N and 12.1% P. Liquid Herbicide (R/T 540, Monsanto Canada, Winnipeg, MB) was applied June 6th at 0.82 L/ha and June 20th at 1.66 L/ha. Corn heat units were calculated for each day using historical weather data obtained from the Saskatoon RCS weather station according to the following calculation:

$$\text{Daily CHU} = \frac{[1.8\ (Tmin - 4.4) + 3.3\ (Tmax - 10) - 0.084\ (Tmax - 10)^2]}{2}$$

Corn silage was harvested after 1,940 CHU using a kernel processor (2-mm roller gap) and at a theoretical chop length of 0.95 cm on August 30th at 32% whole-plant DM. Silage was treated with an inoculant (Biomax 5, Chr. Hansen Inc., Milwaukee, WI) at a rate of 1.0×10^{11} lactic acid bacteria CFU/tonne during ensiling.

The barley variety used for silage production was CDC Copeland (SeCan, Kanata, ON). Barley was seeded at 108 kg/ha on May 19, 2016. Prior to seeding, seed was treated with a fungicide (Rancona Pinnacle, Arysta Lifescience Canada Inc., Guelph, ON) at a rate of 325 mL/100 kg of seed. Anhydrous ammonia was applied to deliver 64.56 kg of N/ha along with 1.36 MT of 12-40-0 10 S 1 Zn (MicroEssentials SZ, The Mosaic Company, Plymouth, MN). Curtail M Herbicide (Dow AgroSciences LLC, Indianapolis, IN) was selectively applied to the field on June 6th at a rate of 1.98 L/ha and a combination of 0.99 L each of Buctril M Emulsifiable Selective Weedkiller (Bayer CropScience Inc., Calgary, AB) and Bison 400L (ADAMA Agricultural Solutions Canada Ltd., Winnipeg, MB) were applied on June 14th, 2016. Barley silage harvest occurred between July 27th to 30th at soft dough stage to target a DM of ~35%. Silage was harvested with a theoretical chop length of 0.95 cm and was treated Biomax 5 (Chr. Hansen Inc., Milwaukee, WI) inoculant at a rate of 1.0×10^{11} lactic acid bacteria colony forming units/tonne during ensiling.

Cereal grains were obtained from a commercial feed mill (Canadian Feed Research Centre, North Battleford, SK) and barley was dry-rolled to an average processing index (**PI**) of 66%. Corn was processed ensure that 5% of the sample (wt/wt basis) would pass through a 1-mm sieve. This processing resulted in a PI of 83.0%. Chemical composition of the silage and grain sources used for the duration of the finishing study are presented in Table 3.1.

Table 3.1 Chemical composition of silage and grain sources used for the duration of the study.

	Ingredient			
	Barley silage	Barley grain	Corn silage	Corn grain
Chemical composition, % DM[1]				
DM, %	40.54 ± 3.40	90.15 ± 0.36	35.38 ± 2.33	89.44 ± 1.27
OM	93.92 ± 0.53	97.88 ± 0.16	95.13 ± 0.11	98.38 ± 0.13
CP	10.90 ± 0.56	11.77 ± 0.25	9.57 ± 0.15	8.57 ± 0.21
Starch	22.47 ± 1.55	58.80 ± 1.66	30.17 ± 0.81	71.36 ± 1.33
ADF	27.57 ± 1.55	6.80 ± 0.40	26.00 ± 0.35	3.93 ± 0.25
NDF	44.90 ± 2.36	19.63 ± 2.08	42.70 ± 0.72	10.27 ± 0.38
Ether extract	2.91 ± 0.13	2.18 ± 0.10	2.93 ± 0.02	4.22 ± 0.42
Ca	0.31 ± 0.06	0.06 ± 0.01	0.25 ± 0.01	0.02 ± 0.01
P	0.26 ± 0.02	0.35 ± 0.02	0.26 ± 0.01	0.32 ± 0.02
NE_m, Mcal/kg[2]	1.52 ± 0.07	1.94 ± 0.02	1.61 ± 0.02	2.14 ± 0.02
NE_g, Mcal/kg[2]	0.93 ± 0.07	1.30 ± 0.02	1.01 ± 0.02	1.46 ± 0.02

[1] Chemical composition is expressed as means ± standard deviation (n = 3).

[2] Net energy values were calculated from feed samples using the NRC (2001) equations.

3.3.2 Steer Management, Experimental Design, and Dietary Treatments

A total of 288 commercial crossbred steers were purchased from a local auction market and used in a previous study until reaching a mean body weight (**BW**) of 465 ± 28 kg. One day prior to the start of the study, steers were implanted with 120 mg of trenbolone acetate and 24 mg of estradiol (Revalor-S, Merck Animal Health, Madison, NJ). Steers were stratified by BW into 1 of 24 pens (12 steers/pen) with the average BW of each pen being 464 kg ± 1.7 kg (mean ± SD). Pens were then randomly assigned to 1 of 6 treatments (described below). Steers were housed in pens measuring 12 × 24 m with a 3.3-m high windbreak (20 cm/m porosity) fence along the back of each pen.

Dietary treatments were arranged in a 2 × 3 factorial with silage source: corn silage (**CS**) or barley silage (**BS**) included at 8% (dry matter basis; Table 3.2) and cereal grain source: dry-rolled barley grain (**BG**; 86% of DM); dry-rolled corn grain (**CG**; 85% of DM); or an equal blend of barley and corn grain (**BCG**; 85% of DM). Steers were gradually transitioned to their respective finishing diet over 24 d (Table 3.3). All diets were formulated to be similar in crude protein (**CP**) and to have the same forage inclusion and mineral and vitamin concentrations. The mineral supplement contained monensin (Elanco Animal Health, Greenfield, IN) to target a final dietary concentration of 33 mg/kg. Steers were fed once daily between 0830 h and 1100 h with the amount of feed delivered targeted to achieve ad libitum intake while also minimizing residual feed.

3.3.3 Growth Performance and DMI

Measurements obtained during the dietary transition period were included when calculating overall performance. The BW of individual steers was measured on two consecutive days at the start and end of the study and the average BW was calculated to determine initial and final BW. Throughout the study, steers were weighed every two weeks with BW data used to calculate ADG by regressing BW with day of study. On weigh days, cattle BW measurements were initiated at 0830 h and feeding was delayed to reduce the effect of gut fill on BW. Feed bunks were also cleaned and the residual feed was weighed and sampled to determine dry matter (**DM**) concentration. The difference in weight between the amount of DM offered and quantity of DM refused was used to determine the bi-weekly pen DMI. These values were then used to determine the average DMI represented as kg/steer/d.

Table 3.2 Ingredients and chemical composition of diets used during the finishing period.

	Barley silage			Corn silage		
	Barley grain	Corn grain	Blend	Barley grain	Corn grain	Blend
Ingredient, % DM						
Barley silage	8.00	8.00	8.00	-	-	-
Corn silage	-	-	-	8.00	8.00	8.00
Barley grain	85.94	-	42.72	85.86	-	42.69
Corn grain	-	84.96	42.72	-	84.89	42.69
Urea	-	0.98	0.50	0.08	1.06	0.57
Mineral pellet [1]	5.56	5.56	5.56	5.56	5.56	5.56
Limestone	0.50	0.50	0.50	0.50	0.50	0.50
Chemical composition, % DM [2]						
DM, %	82.2 ± 1.07	81.7 ± 0.83	82.0 ± 0.81	80.0 ± 0.95	79.9 ± 1.65	80.1 ± 1.28
OM	95.6 ± 0.10	96.0 ± 0.16	95.8 ± 0.03	95.7 ± 0.14	96.1 ± 0.11	95.9 ± 0.02
CP	11.5 ± 0.17	11.3 ± 0.18	11.5 ± 0.14	11.6 ± 0.21	11.4 ± 0.20	11.5 ± 0.17
NDF	21.6 ± 1.57	13.5 ± 0.50	17.5 ± 0.53	21.4 ± 1.82	13.3 ± 0.26	17.3 ± 0.78
ADF	8.4 ± 0.44	5.9 ± 0.34	7.1 ± 0.31	8.3 ± 0.33	5.8 ± 0.24	7.0 ± 0.16
Starch	54.2 ± 1.43	64.5 ± 1.17	59.3 ± 0.27	54.7 ± 1.35	65.1 ± 1.23	59.9 ± 0.15
Ether extract	2.3 ± 0.08	4.0 ± 0.35	3.2 ± 0.22	2.3 ± 0.09	4.0 ± 0.36	3.2 ± 0.23
Ca	0.86 ± 0.03	0.83 ± 0.03	0.84 ± 0.03	0.86 ± 0.03	0.82 ± 0.02	0.84 ± 0.03
P	0.35 ± 0.02	0.32 ± 0.02	0.34 ± 0.01	0.35 ± 0.02	0.32 ± 0.02	0.34 ± 0.01
NE_m, Mcal/kg [3]	1.85	2.00	1.93	1.86	2.00	1.93
NE_g, Mcal/kg [3]	1.23	1.35	1.29	1.23	1.36	1.30

[1]The mineral pellet supplement was mixed with ground barley grain for pelleting using on a ratio of 78:21 (DM basis), respectively. On DM basis, the mineral supplement (excluding the barley grain) contained 9.2% of calcium, 0.32% of phosphorus, 1.64% sodium, 0.28% of magnesium, 0.60% of potassium, 0.12% of sulfur, 4.9 mg/kg of cobalt, 185 mg/kg of copper, 16.6 mg/kg of iodine, 84 mg/kg of iron, 500 mg/kg of manganese, 2 mg/kg of selenium, 558 mg/kg of zinc, 40 000 IU/kg of vitamin A, 5000 IU/kg of vitamin D3, and 600 IU/kg of vitamin E. The final supplement contained 510 mg/kg of monensin (Elanco Animal Health, Greendfield, IN) on a DM basis.

[2]Chemical composition is expressed as means ± standard deviation (n = 3).

[3]Net energy values were calculated from feed samples using the NRC (2001) equations.

Table 3.3 Ingredient composition of transition diets used to transition steers to their respective finishing diets over 24 d, each step was 4 d in duration with the final diet being fed on d 25.

	Stage of Transition						
Ingredient, % DM	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Final
BS-BG							
Barley silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	31.44	44.44	55.44	65.94	73.94	80.94	85.94
Canola meal	8.00	5.00	4.00	3.00	2.00	1.00	0.00
Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56	5.56
BS-CG							
Barley silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Corn grain	30.97	42.94	54.74	65.74	73.94	80.96	84.96
Canola meal	8.00	6.00	4.00	3.00	2.00	0.00	0.00
Urea	0.47	0.50	0.70	0.70	0.80	0.98	0.98
Limestone	0.00	0.00	0.00	0.00	0.50	0.50	0.50
Mineral pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56	5.56
BS-BCG							
Barley silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	15.61	22.07	27.57	33.22	37.22	40.72	42.72
Corn grain	15.61	22.07	27.57	33.22	37.22	40.72	42.72
Canola meal	8.00	5.00	4.00	2.00	1.00	0.00	0.00
Urea	0.22	0.30	0.30	0.50	0.50	0.50	0.50
Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56	5.56
CS-BG							
Corn silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	31.17	44.24	55.29	65.84	73.86	80.86	85.86
Canola meal	8.00	5.00	4.00	3.00	2.00	1.00	0.00
Urea	0.27	0.20	0.15	0.10	0.08	0.08	0.08
Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56	5.56
CS-CG							
Corn silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Corn grain	30.72	42.72	54.64	65.54	72.94	79.94	84.89
Canola meal	8.00	6.00	4.00	3.00	2.00	1.00	0.00
Urea	0.72	0.72	0.08	0.90	1.00	1.00	1.05
Limestone	0.00	0.00	0.00	0.00	0.50	0.50	0.50
Mineral pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56	5.56
CS-BCG							
Corn silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	15.47	21.97	27.47	32.72	36.72	40.22	42.69
Corn grain	15.47	21.97	27.47	32.72	36.72	40.22	42.68
Canola meal	8.00	5.00	4.00	3.00	2.00	1.00	0.00
Urea	0.50	0.50	0.50	0.50	0.50	0.50	0.57

Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56	5.56

[1]The mineral pellet supplement was mixed with barley grain for pelleting on a DM basis ratio of 78:21, respectively. On DM basis, the mineral supplement (excluding the barley grain) contained 9.2% of calcium, 0.32% of phosphorus, 1.64% sodium, 0.28% of magnesium, 0.60% of potassium, 0.12% of sulfur, 4.9 mg/kg of cobalt, 185 mg/kg of copper, 16.6 mg/kg of iodine, 84 mg/kg of iron, 500 mg/kg of manganese, 2 mg/kg of selenium, 558 mg/kg of zinc, 40 000 IU/kg of vitamin A, 5000 IU/kg of vitamin D3, and 600 IU/kg of vitamin E. The final supplement contained 510 mg/kg of monensin (Elanco Animal Health, Greenfield, IN) on a DM basis.

On the same days as BW measurement, representative samples of barley silage, barley grain, corn silage, corn grain, urea, limestone, mineral and vitamin pellet, and canola meal were collected. All samples of feed ingredients as well as samples of refusals were dried in a forced-air oven at 55°C for 72 h for DM determination. The DM content of each ingredient was used to ensure that the as fed ingredient inclusion achieved dietary formulation specifications. Dried feed samples were then composited by month (n = 3) on an equal weight basis. Concentrate samples (corn grain, barley grain, mineral pellet, and canola meal) were ground using a Retch ZM 200 grinder (Haan, Germany) to pass through a 1-mm screen while silage samples were ground through a 1-mm screen using a hammer mill (Christie-Norris Laboratory Mill, Christie-Norris Ltd, Chelmsford, UK). All dried and ground feed samples were submitted for chemical analysis to Cumberland Valley Analytical Services (Waynesboro, PA) for determination of DM, OM, CP, NDF, ADF, starch, ether extract, calcium, and phosphorus concentrations. For silage, DM was determined using a modified procedure that combined a partial DM adapted from Goering and Van Soest (1970) followed by heating samples to 105ºC for 3 h according to method 2.1.4 (National Forage Testing Association, 2006). For all other feeds, DM was determined by drying samples at 135ºC using AOAC (2000) method 930.15. Ash was determined using AOAC (2000) method 942.05 with the modification of using 1.5-g sample weight with a 4 h ashing time, followed by hot weighing. Ash content was used to determine the OM concentration by subtracting ash from 100%. Crude protein was determined using AOAC (2000) method 990.03 using a LECO FP-528 Nitrogen Combustion Analyzer (LECO, St. Joseph, MI). Neutral detergent fibre was determined using the method of Van Soest et al. (1991) including α-amylase and sodium sulfite, and acid detergent fiber was determined using AOAC (2000) method 973.18, both with the modification that Whatman 934-AH (GE Healthcare Life Sciences, Chicago, IL) glass 1.5 um micro-fiber filters were used in place of a fritted glass crucible. Starch concentration was determined with correction for free glucose as described by Hall (2009). Ether extract was determined according to AOAC (2000) method 2003.05 using the Tecator Soxtec System HT 1043 Extraction unit (Tectator, Foss, Eden Prairie, MN). Calcium and phosphorus content were determined according to AOAC (2000) method 985.01 with the modification that a 0.35 g sample was ashed for 1 h at 535ºC, digested in open crucibles for 25 min in 15% nitric acid on a hotplate, diluted to 50 mL, and analysed on axial view using a Perkin Elmer 5300 DV ICP (Perkin Elmer, Shelton, CT). Finally, the net energy values (**NE**) of feed were calculated using NRC (2001) equations.

At the end of the study (89 d on feed), steers were transported to a federally inspected abattoir (Cargill Meat Solutions, High River, AB). Hot carcass weight, back fat thickness, and rib eye area were measured between the 12th and 13th rib. The Canadian Beef Grading Agency yield and quality grades as well as marbling score were determined using the Computer Vision Grading System (VBG 2000 e+v Technology GmbH, Oranienburg, Germany). Liver scores were determined using the Elanco Liver Check System (Elanco Animal Health, Greenfield, IN).

Net energy values for maintenance (NE_m) and gain (NE_g) were calculated based on animal performance as described by Zinn et al. (2002). The retained energy (**RE**) for large framed yearling calves used $RE=[0.0437BW_{0.75}] \times ADG_{1.097}$ (National Research Council (NRC), 1984) where BW was the shrunk (4% shrink) mid test weight. Net energy of gain was determined from NE_m according to Zinn and Shen (1998) using the equation: $NE_g = NE_m \times 0.877 – 0.41$.

3.3.4 Near Infrared Estimated Digestibility and Fecal Composition

On d 51 of the study, fecal samples were collected from each pen. Approximately 1 L of fresh feces were collected from pats produced by at least 4 steers in each pen, while avoiding contamination with bedding or soil from the pen floor (Jancewicz et al., 2016a). The total number of fecal pats collected per pen was recorded. Composited fecal samples were thoroughly mixed and a 250-mL sub-sample was weighed, diluted in 250 mL of tap water, and screened using a 1.18 mm screen. The sample was continuously rinsed with tap water until only solid material remained. The residue was then dried for 24 h at 55◦C, and sorted according to grain type (corn or barley) and fibrous portions. Material retained on the screen was further sorted into whole, fractured grain kernels, and fibre. The weight of the sorted fractions was then used to estimate the source and amount of grain kernels in the feces. The remaining composite sample of feces was dried in a forced-air oven at 55◦C to a constant weight and then ground to pass through a 1-mm screen using a Retsch ZM 200 grinder (Haan, Germany).

Ground fecal samples were analyzed using near infrared (**NIR**) spectroscopy to estimate apparent total-tract digestibility using previously developed calibration equations as described by (Jancewicz et al., 2016b). For each pen, quartz ring cups were evenly filled and packed with the dried and ground fecal samples and scanned in duplicate using two repacks with the second scan utilizing a separate subsample from the original sample. Samples were scanned using a SpectraStar

Near-Infrared analyzer 2400 RTW (Unity Scientific, Brookfield, CT, USA). Spectral information was collected at wavelengths between 1200 and 2400 nm in 1 nm increments.

3.3.5 Statistical Analysis

Data were analysed with pen as the experimental unit using the mixed model of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) with the fixed effect of silage source, grain source, and the 2-way interactions. Yield grades, quality grades, liver scores, and marbling scores were analyzed using the GLIMMIX procedure of SAS (SAS version 9.4, SAS Institute, Inc. 2002) with a binominal error structure and logit data transformation.

For grain kernels isolated from feces, data were analyzed using the mixed model of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) with the fixed effect of silage source, grain source, and the 2-way interaction. When data were not normally distributed, the GLIMMIX procedure of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) was used with binominal error structure and logit data transformation. For variables where all observations within a treatment were not possible (e.g., appearance of corn in feces from steers fed diets only containing barley), the individual treatment was excluded from analysis for that specific variable and kernel appearance was denoted as not present (**NP**). For all analysis, when the P value for grain type or the interaction was < 0.05, means were separated using the Tukey's test.

3.4 Results

3.4.1 Growth Performance and Carcass Characteristics

Initial and final BW were not affected by cereal silage source, cereal grain source, or the interaction ($P \geq 0.20$; Table 3.4). Feeding CG increased ($P < 0.01$) DMI by 0.8 and 0.6 kg/d relative to BG and BCG, respectively, but ADG (2.07 kg/d) did not differ among treatments ($P > 0.05$). As a result, G:F was greater ($P = 0.04$) for BG (0.172 kg/kg) than CG (0.162 kg/kg), but did not differ from BCG (0.165 kg/kg). Silage source did not affect DMI, ADG, or G:F. Hot carcass weight was 6.2 kg greater ($P < 0.01$) and dressing percent was 0.57 percentage units greater ($P = 0.04$) for steers fed CS than BS, respectively. Grain source did not affect hot carcass weight or dressing percentage.

Table 3.4 Effect of cereal silage source (8% of DM) and cereal grain source (86% of DM) on DMI, BW, ADG, G:F, and carcass characteristics for finishing steers (12 steers/pen with 4 pens/treatment).

	Barley silage			Corn silage			SEM[1]	*P*-Value		
	Barley	Corn	Blend	Barley	Corn	Blend		Silage	Grain	S × G[2]
Initial BW, kg	464	464	464	464	466	464	0.80	0.30	0.20	0.30
Final BW, kg	648	647	645	654	651	649	4.93	0.25	0.71	0.99
DMI, kg/d	12.1_{b}	12.8_{a}	12.3_{b}	12.3_{b}	13.2_{a}	12.4_{b}	0.22	0.23	< 0.01	0.79
ADG, kg/d	2.05	2.05	2.04	2.13	2.10	2.05	0.05	0.25	0.60	0.70
G:F, kg/kg	0.170_{a}	0.163_{b}	0.165_{ab}	0.173_{a}	0.160_{b}	0.165_{ab}	0.004	1.00	0.04	0.79
Hot carcass, kg	365	368	365	372	375	370	2.05	< 0.01	0.17	0.85
Dressing, %	58.7	59.2	59.0	59.2	60.0	59.4	0.31	0.04	0.14	0.80
Back fat, cm	1.09	1.12	1.19	1.14	1.19	1.12	0.06	0.57	0.76	0.37
Rib eye area, cm^2	88.98	87.80	88.68	91.55	89.83	91.53	0.57	0.05	0.56	0.96
Yield Grade, %[4]										
CBGA 1	47.9	47.9	37.5	50.0	34.0	40.8	7.2	0.63	0.36	0.42
CBGA 2	47.9	37.5	45.8	29.2	53.2	40.8	7.3	0.62	0.61	0.08
CBGA 3	4.2	12.5	16.7	18.8	12.8	18.4	5.6	0.13	0.30	0.24
Quality Grade, %[3]										
CBGA AAA	79.2	83.3	75.0	75.0	78.7	67.4	6.7	0.30	0.30	0.98
CBGA AA	20.8	14.6	25.0	22.9	21.3	32.7	6.7	0.28	0.22	0.89
CBGA A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.00	1.00	1.00
CBGA B	0.0	2.1	0.0	2.1	0.0	0.0	2.1	1.00	1.00	1.00
Marbling score, %[4]										
Moderate	2.1	0.0	0.0	0.0	4.3	2.0	2.9	0.99	1.00	1.00
Modest	6.2	4.2	14.6	6.3	12.8	14.3	5.1	0.38	0.15	0.46
Small	54.2	72.9	56.2	45.8	48.9	38.8	7.3	0.01	0.16	0.52
Slight	37.5	22.9	29.2	47.9	34.0	44.9	7.2	0.04	0.15	0.91
Trace	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.00	1.00	1.00
Liver Scores[5]										
Clear	68.0	73.3	76.6	79.2	71.7	63.0	7.1	0.85	0.85	0.20
Minor	32.0	22.2	19.1	20.8	28.3	23.9	6.6	0.98	0.74	0.34
Severe	0.0	4.4	4..3	0.0	0.0	13.0	5.0	0.99	1.00	1.00
NE_m, Mcal/kg[6]	1.98_{a}	1.89_{b}	1.92_{ab}	2.00_{a}	1.86_{b}	1.96_{ab}	0.03	0.87	< 0.01	0.68

NE_g, Mcal/kg[6]	1.33[a]	1.24[b]	1.28[ab]	1.34[a]	1.22[b]	1.30[ab]	0.03	0.89	< 0.01	0.73

[a,b,c]Values within a row with uncommon letters differ among grain sources ($P < 0.05$).

[1]Greatest SEM was reported.

[2]S × G = silage by grain interaction.

[3]Percent of total according to Canadian Beef Grading Agency (CBGA)

[4]Percent of total according to United States Department of Agriculture (USDA) where 600–699 = moderate; 500–599 = modest; 400–499 = small; 300–399 = slight; and 200– 299 = trace.

[5]According to Elanco Liver Check System (Elanco Animal Health, Greenfield, IN, USA).

[6]Net energy values calculated based on animal performance for the finishing period as described by Zinn et al. (2002) and Zinn and Shen (1998)

There was no effect of silage or cereal grain source on back fat thickness, ribeye area, yield grades, or quality grades. For marbling scores, the percentage of carcasses grading small was greater for BS relative to CS (61.6 vs. 44.5%; $P = 0.01$), while CS had a greater percentage of carcasses grading slight relative to BS (42.3 vs. 29.9%; $P = 0.04$). There were no differences ($P > 0.05$) in the severity of liver abscesses among steers fed differing silage or cereal grain sources with 72.0% of carcasses having no evidence of abscesses, 24.4% with minor liver abscesses, and 3.6% with severe liver abscesses. The NE_m and NE_g, calculated based on steer performance, were greater for BG compared to CG, but not different from BCG ($P < 0.01$) and did not differ between silage sources.

3.4.2 Estimated Total-Tract Digestibility and Fecal Composition

There was no effect of silage source on predicted total-tract digestibility of DM, OM, NDF, ADF, or CP digestibility ($P > 0.05$; Table 3.5). However, predicted starch digestibility was greater (87.1 vs. 85.8%; $P = 0.02$) for BS than CS. Digestibility of DM and CP were greater for BG relative to CG or BCG ($P < 0.01$). Organic matter, NDF, and starch digestibility were greatest for BG, intermediate for BCG, and the least for CG ($P < 0.01$). In general, fecal starch concentrations were high, but fecal starch content was greatest for CG, least for BG, and intermediate for BCG ($P < 0.01$). Predicted gross energy digestibility was greatest ($P < 0.01$) for BG relative to other grain sources and not affected by silage source.

More ($P < 0.01$) whole barley kernels appeared in the feces of cattle fed BG, intermediate for BCG, and the least for CG (Table 3.6). More fractured barley kernels were present in the feces of cattle fed BG ($P = 0.04$). Whole corn kernels in feces were not affected by diet, but more fractured kernels were observed for CS than BS ($P = 0.04$). Likewise, fractured corn kernels were most common in feces from cattle fed CG, intermediate for BCG, and least for BG ($P < 0.01$), and greater for CS than BS ($P = 0.04$). Fibrous (non-kernel) content in feces was greater for BG, intermediate for BCG, and least for CG diets ($P < 0.01$), and greater for BS than CS ($P = 0.02$).

Table 3.5 Effect of cereal silage (8% of DM) and cereal grain source (86% of DM) on apparent total-tract digestibility in steers during the finishing period using NIR calibrations (Jancewicz et al., 2016) on feces collected on d 51 of the study.

	Barley silage			Corn silage			SEM	*P* - Values		
	Barley	Corn	Blend	Barley	Corn	Blend		Silage	Grain	S × G[1]
Digestibility, % DM basis										
DM	84.4$_{a}$	77.2$_{b}$	78.0$_{b}$	83.0$_{a}$	78.0$_{b}$	79.5$_{b}$	0.75	0.63	< 0.01	0.17
OM	85.7$_{a}$	74.0$_{c}$	76.1$_{b}$	83.3$_{a}$	74.2$_{c}$	77.3$_{b}$	0.77	0.60	< 0.01	0.08
CP	73.2$_{a}$	67.6$_{b}$	67.1$_{b}$	72.7$_{a}$	66.4$_{b}$	67.5$_{b}$	0.87	0.57	< 0.01	0.68
NDF	61.5$_{a}$	52.0$_{c}$	56.4$_{b}$	59.8$_{a}$	52.0$_{c}$	56.3$_{b}$	0.61	0.24	< 0.01	0.31
ADF	30.3$_{a}$	28.1$_{b}$	26.3$_{ab}$	29.9$_{a}$	26.1$_{b}$	29.3$_{ab}$	1.08	0.84	0.03	0.10
Starch	92.5$_{a}$	83.0$_{c}$	85.9$_{b}$	90.1$_{a}$	82.3$_{c}$	85.0$_{b}$	0.63	0.02	< 0.01	0.33
Fecal starch, % DM	14.5$_{c}$	32.4$_{a}$	26.0$_{b}$	15.8$_{c}$	32.3$_{a}$	28.0$_{b}$	1.35	0.33	< 0.01	0.72
GE digestibility, %	88.4$_{a}$	81.6$_{b}$	83.2$_{b}$	89.0$_{a}$	84.1$_{b}$	84.8$_{b}$	1.16	0.12	< 0.01	0.71

$_{a,b,c}$ Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

[1]S × G = silage by grain interaction.

Table 3.6 Effects of cereal silage (8% of DM) and cereal grain source (86% of DM) on the composition of solids retained on a 1.18 mm sieve after wet screening a 250 mL subsampled fecal composite collected from pen floors on d 51 of the study.

	Barley silage			Corn silage				*P* - Values		
	Barley	Corn	Blend	Barley	Corn	Blend	SEM[1]	Silage	Grain	S × G[2]
Wet fecal weight, g/250mL	240.2$_b$	259.6$_a$	245.1$_b$	243.9$_b$	259.1$_a$	246.7$_b$	4.33	0.65	< 0.01	0.89
Total solids retained, g[3]	17.4$_c$	43.1$_a$	35.2$_b$	20.6$_c$	44.5$_a$	35.8$_b$	1.95	0.29	< 0.01	0.81
Whole barley, % retained	21.11$_a$	1.30$_c$	9.61$_b$	21.30$_a$	NP	7.33$_b$	0.71	0.13	< 0.01	0.07
Fractured barley, % retained	1.69$_a$	0.19$_b$	1.57$_b$	6.20$_a$	NP	1.48$_b$	0.48	0.10	0.04	0.08
Whole corn, % retained	NP	0.71	0.72	0.48	1.37	1.42	0.40	0.08	0.14	0.96
Fractured corn, % retained	NP	66.65$_a$	42.36$_b$	2.69$_c$	70.43$_a$	51.02$_b$	2.78	0.04	< 0.01	0.40
Fibre, % retained	77.20$_a$	31.17$_c$	44.73$_b$	68.48$_a$	28.20$_c$	38.75$_b$	2.70	0.02	< 0.01	0.58

[a,b,c] Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

NP = Not present. Data were not included in statistical analysis as there was no supply of the specific grain source and fecal analysis confirmed that none were present.

[1]Greatest SEM was reported.

[2]S × G = silage by grain interaction.

[3]Total weight of dry solid material that was retained on a 1.18 mm sieve after rinsing a 250-mL fecal sample under tap water.

3.5 Discussion

We hypothesized that diets containing a blend of corn and barley grain would have greater digestibility, growth performance, and feed efficiency compared to single grain diets. Though not examined when feeding a combination of dry-rolled corn and dry-rolled barley, several studies have demonstrated synergistic effects on growth performance and feed efficiency for finishing cattle fed a combination of grain sources that differ in their ruminal fermentability. Stock et al. (1987a, 1987b) demonstrated, in multiple studies, a positive associative effect of combining high-moisture corn with diets comprised of whole corn grain or dry-rolled sorghum grain, noting an improvement in feed efficiency and ADG for blended grain diets. Additionally, Stock et al. (1987b) found that feeding a combination of grain sources improved ruminal and total-tract starch digestion, an observation that may partially explain the positive impact of this practice on feed efficiency. In another study, Huck et al. (1998) observed positive associative effects of feeding steam-flaked sorghum in combination with high-moisture or dry-rolled corn noting improvements in ADG and G:F. A similar study conducted by Kreikemeier et al. (1987) indicated that with wheat, which had 35% more digestible starch than dry-rolled corn, ADG and G:F were improved when wheat was included with corn in finishing diets as compared to when either grain source was fed alone. For dairy cattle, Khorasani et al. (2001) demonstrated an increase in milk and milk component yield in primiparous cows fed an equal blend of coarse ground corn and barley grain relative to individual grain-based diets. Those authors suggested that improvements were due in part to synchronization of dietary energy and protein with the blended grain diet. As such, there is a large body of support suggesting that there may be potential additive benefits to combining grain sources that have varying rates and extents of starch degradation. However, no additive effects of feeding a blend of carbohydrate sources were detected in this study. It is possible that the cereal grain processing method imposed in the current study was inadequate to improve fermentability sufficiently enough to observe additive effects or that differences in the fermentability of the grain sources were small.

3.5.1 Effects of Cereal Silage Source

Although inclusion rates of silage were low (8% of DM), we observed that CS improved hot carcass weight, and dressing percentage relative to diets with BS. Given the relatively low inclusion rate, these observations are difficult to explain. However, it is possible that numerically greater starch concentration in CS may have contributed to greater quantity of digestible starch supply to the rumen and potentially the intestine relative to BS (Table 3.1). Owens et al. (1986) estimated that starch digested in the small intestine may provide up to 42% more energy than when fermented in the rumen. While this suggestion may provide a potential explanation, given the high fecal starch content in general, and particularly that of CG fed steers (> 30% DM), it could be expected that limits to intestinal starch digestion may have been exceeded (Huntington et al., 2006). Secondly, fat provided by corn-based diets is generally greater in content and of different composition than that provided by barley which, given its greater energy value relative to carbohydrates, would increase energy intake and could relate to carcass quality improvement (Table 3.1). However, the contribution of silage towards energy supply, at such low levels of inclusion is unlikely to stimulate carcass gain, particularly considering that there were no differences in predicted NDF or ADF digestibility among silage sources. The most reasonable explanation is that although only numerically different, the greater estimated gross energy digestibility of CS treatments, as well as increased starch and NE for CS (Table 3.1) when compounded over the 89-d finishing study may have increased total energy intake and subsequently resulted in improvements in carcass quality. Although not significant, the additional energy intake may have been sufficient to result in the improvements in carcass gain observed. Interestingly, when energy density was predicted based on growth performance, no differences were detected and silage source did not affect DMI. However, the equations of Zinn et al. (2002) and Zinn and Shen (1998) use shrunk live BW rather than carcass weight, a potential flaw when using this method in cases where there are differences in hot carcass weight.

Interestingly, feeding BS increased the appearance of whole barley kernels in the feces. When feeding CS, the appearance of whole and fractured corn kernels in the feces were also increased. With finishing diets, it is generally assumed that the appearance of grain in the feces may be an indication of inadequately processed cereal grain. However, despite the fact that CS was harvested using a kernel processor (2 mm gap width) there was still an influence of silage source on kernel appearance in the feces. Previous studies have suggested that kernel processing through a 2-mm gap should be sufficient to optimize starch digestibility in corn silage (Ferraretto and Shaver, 2012). However, such processing conditions may not be adequate with finishing diets or with short-season corn varieties. For barley kernel appearance in the feces, it is evident that the majority of whole kernels arise from the grain source as opposed to the silage source, suggesting that not all kernels were adequately damaged during the dry rolling process despite achieving an adequate processing index.

3.5.2 Effects of Cereal Grain Source

In the current study, there were no observed benefits to feeding a combination of dry-rolled barley and corn grain. In fact, feeding BG improved G:F and had greater predicted digestibility compared to CG or BCG. Several studies have been conducted directly comparing dry-rolled BG and CG although results have been inconsistent with regards to feed intake and growth performance given the reported differences in energy value between these grain sources. Consistent with results in the current study, studies by Boss and Bowman (1996) and Milner et al. (1995) both demonstrated an increase in DMI for steers fed dry-rolled corn compared to barley. Boss and Bowman (1996) also reported that feed efficiency was greater for barley fed steers compared to those fed dry-rolled corn. In contrast, studies by Mathison and Engstrom (1995) reported that when dry-rolled, no effect of grain source (corn vs. barley) was observed on intake or growth performance. Nelson et al. (2000) reported that steers fed dry-rolled corn were more efficient than those fed dry-rolled barley. The greater DMI and G:F observed for barley in the current study are most likely influenced by the less severe processing of corn grain and consequently reduced digestibility relative to barley grain. Supporting this, fecal starch for all treatments was high in this study. Jancewicz et al. (2017) reported a mean fecal starch of 7% when evaluating 282 fecal samples from 6 feedlots in southern Alberta. Although the study only evaluated diets containing barley grain or a combination of barley and wheat, they observed a quadratic relationship between fecal starch and G:F, and a high PI was also correlated with higher fecal starch. Given the high fecal starch and low digestibility for CG in the present study, these results support that dry-rolling corn is not a processing method sufficient to disrupt the complex starch and protein matrix of corn grain and subsequently improve digestibility (Owens et al., 1997; Zinn et al., 2011). For barley, even with a mean PI of 66.6% in the current study, fecal starch for the BS-BG treatment was still 14.5%, substantially greater than observed by Jancewicz et al. (2017). Although PI was more severe for BG, it is possible that large variability in kernel size may have resulted in a non-uniform processing and that a portion of smaller kernels may have remained unprocessed, as further evidenced by whole kernel appearance in feces. Such processing conditions would explain the lower than expected starch digestibility for BG as well as the higher fecal starch content, given that whole barley has poor digestibility. However, it should be noted that despite high fecal starch, ADG still exceeded 2 kg/d for all treatments.

In feedlot diets, DMI is predominantly influenced by metabolic factors (Allen et al., 2009). Net energy values published by the National Academy of Science, Engineering, and Medicine (NASEM; 2016) suggest that dry-rolled corn should have a greater energy content than dry-rolled barley (2.17 vs. 2.06 Mcal/kg NE_m, respectively). However, when calculated based on performance, NE values were greater for BG than CG. The relationship between NE and DMI has been well established such that dietary NE_m content can be used to predict DMI (NASEM, 2016). Predictions developed by both NASEM (2016) and Anele et al. (2014) demonstrate that DMI decreases with increasing NE_m. As such, it is likely that the lower performance, as calculated NE_m, as well as the lower digestibility of CG were driving factors behind the greater DMI for CG-fed steers, despite there being no increase in growth performance. Additionally, the low processing index of CG may explain the low energy utilization. Likewise, greater digestibility of BG diets may have reduced feed intake, the extent to which likely limited a corresponding improvement in ADG or G:F.

Not surprisingly, appearance of whole barley kernels in the feces was greater for BG diets, while whole and fractured corn kernel appearance were greatest on CG diets. Results suggest that at least for CG, a PI of 83% resulted in a large amount of bypass starch. These results reinforce the importance of adequate grain processing in finishing diets to maximize feed utilization, while also minimizing the risk of digestive upsets such as acidosis that can occur when feeding over processed grains.

Contrary to our hypothesis, feeding a blend of dry-rolled corn and barley grain showed no benefit with respect to growth performance or carcass characteristics for finishing beef cattle. Current results indicate that when dry-rolled, feeding BG resulted in improved performance and digestibility compared to either CG or BCG. Despite low inclusions levels (8% of DM), feeding CS improved carcass characteristics relative to BS and no interactions were detected between silage and grain sources, indicating there were no observed additive benefits of concurrently feeding BG with CS.

4.0 USE OF BARLEY OR CORN SILAGE WITH BARLEY, CORN, OR A BLEND OF BARLEY AND CORN GRAIN ON RUMEN FERMENTATION, TOTAL-TRACT DIGESTIBILITY, AND NITROGEN BALANCE FOR FINISHING BEEF HEIFERS

4.1 Abstract

Five ruminally cannulated heifers were used in an incomplete 6 × 6 Latin square design to determine the effects of cereal silage (barley vs. corn) and cereal grain (barley vs. corn vs. a 50:50 blend of barley and corn) inclusion on dry matter intake, ruminal fermentation, total-tract digestibility, nitrogen balance, and cereal grain appearance in feces. Corn silage (**CS**) or barley silage (**BS**) were included at 8% of diet DM. Within each silage source, diets contained either dry-rolled barley (**BG**; 86% of DM), dry-rolled corn (**CG**; 85% of DM), or an equal blend of barley and corn (**BCG**; 85% of DM). Each period was 25-d, with 5 d of dietary transition, 13 d of dietary adaptation, and 7 d of data and sample collection. Samples collected included feed and refusals, total urine and feces and rumen fluid. All data, except fecal kernel appearance, were analyzed using the Mixed Model of SAS with the fixed effects of silage (**S**), grain (**G**), and the 2-way interaction (**S × G**). Dry matter intake and mean ruminal pH were not affected by diet. Total SCFA concentrations were greater for BCG than BG or CG (G, $P < 0.01$) and for CS (S, $P < 0.01$) relative to BS. The molar proportion of acetate was greatest for BS-BG and BS-CG (S × G, $P < 0.01$), while the molar proportion of propionate was greatest for CS-BG (S × G, $P < 0.01$). Rumen ammonia-N concentrations were greater for CG than BG or BCG (G, $P < 0.01$), and greater for CS compared to BS (S, $P = 0.02$). Apparent total-tract digestibility of DM, OM, aNDFom, starch, and gross energy were greatest for BG (G, $P \leq 0.04$). Dietary digestible energy content (Mcal/kg) was greater for BG (G, $P = 0.03$) than CG and BCG. Total N retention (g/d and % of intake) was greatest for CS-BG (S × G, $P \leq 0.03$) relative to all other treatments. *In situ* degradation rates of DM, CP, and starch were greater for BG than CG ($P < 0.01$). The potentially degradable fraction of DM, CP, and starch were greater for CG ($P \leq 0.03$), while the undegradable fraction was greater for BG ($P \leq 0.05$). For silage sources, CS had greater 24 h *in situ* DM digestibility ($P < 0.01$) and 24, 48, and 72 hr starch digestibility ($P \leq 0.03$) relative to BS. Results suggest that while feeding a combination of CS and BG promotes propionate production and greater N retention; few other additive effects were observed.

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4.2 Introduction

Development of short-season corn varieties has resulted in increased acreage of corn in western Canada (Statistics Canada, 2019a). These newly developed varieties require less corn heat units (CHU) to reach maturity and are optimal for silage production in areas with as few as 2100 CHU. Compared to barley, short-season corn has greater input costs, but a greater yield that may justify the cost differential (Lardner et al., 2017;. Baron et al., 2014). However, there is limited data on the use of short-season corn silage in finishing diets for beef cattle.

Several previous studies have compared corn and barley as grain sources in diets for finishing cattle (Beauchemin and Koenig, 2005; Boss and Bowman, 1996a). Generally speaking, when dry-rolled, starch and protein supplied by barley is more rapidly fermented and more is digested in the rumen than corn grain (Herrera-Saldana et al., 1990). Previous studies have also demonstrated improved growth performance and feed efficiency when feeding a combination of grain sources (Huck et al., 1998; Stock et al., 1987a) differing in their rates of ruminal fermentation (Bock et al., 1991; Stock et al., 1987b). However, there are currently no studies comparing silage source while concurrently comparing combinations of corn and barley grain. The hypothesis of the current study was that diets containing a mixture of grains would optimize ruminal starch and protein degradation resulting in increased total SCFA concentrations, greater total-tract digestibility, and greater bacterial N production. The objective of the current study was to evaluate the effects of combinations of silage type (corn vs. barley) and cereal grain type (corn vs. barley vs. blend) on DMI, ruminal fermentation, total-tract digestibility, fecal pH, and microbial protein supply for finishing beef cattle.

4.3 Materials and Methods

Use of heifers and the procedures used were pre-approved by the University of Saskatchewan Animal Research Ethics Board (protocol 20100021) according to the guidelines of the Canadian Council on Animal Care (Ottawa, ON, Canada).

4.3.1 Silage Production and Cereal Grain Processing

Silage production and cereal grain processing were completed as described in Study 1.

4.3.2 Animal Management, Experimental Design, and Dietary Treatments

Five Hereford-Angus cross yearling heifers (383 ± 29 kg) at the University of Saskatchewan Livestock Research Barn were surgically fitted with a 7.6-cm ruminal cannula (model 3C; Bar Diamond Inc., Parma, ID). Three weeks following surgery, the 7.6-cm cannula was replaced with a 9-cm ruminal cannula (model 9C; Bar Diamond Inc.). For the duration of the study, heifers were housed in individual pens (9 m^2) with ad libitum access to water and rubber mats on the floor. Heifers were fed twice daily at 0930 and 1200 h with feed refusals collected at 0800 h each day. Pens were scraped and washed daily to remove manure. Heifers were allowed 2 h/d of exercise in an outdoor dry lot pen at a frequency the conformed with animal care guidelines.

This study was designed as an incomplete 6 × 6 Latin square design balanced for carry-over effects. The incomplete design allowed for each diet to be tested for each heifer over the 6-period study while addressing a limitation in pen availability. Prior to the start of the study, heifers were gradually transitioned to a barley-based finishing diet over 24 d. The step-up period consisted of 6 steps, each step lasting 4 d (Table 4.1). With each diet, the amount of dry-rolled barley was increased and the amount of barley silage was decreased. The amount of feed offered during the step-up period was restricted to 2.5% of BW on a DM basis in order to control feed intake during adaptation.

Dietary treatments incorporated corn silage (**CS**) or barley silage (**BS**) at 8% of the diet (DM basis; Table 4.2), in combination with dry-rolled barley grain (**BG**; 86% of DM), dry-rolled corn grain (**CG**; 85% of DM), or an equal blend of barley and corn grain (**BCG**; 85% of DM). The remainder of the diets were comprised of limestone, a vitamin and mineral pellet, and urea to make the diets isonitrogenous. The mineral pellet contained monensin (Elanco Animal Health, Greenfield, IN) to target a final dietary concentration of 33 mg/kg. After completion of period 3, one heifer was replaced with a heifer of similar body weight due to health complications. Data for the replaced heifer from the completed periods was used as it was not affected by the health complication.

Each period was 25-d in duration. The first 5 d of each period were used to transition heifers to their respective treatment by incorporating 33% of new diet on d 1 and 2, 66% on d 3 and 4, and 100% in the afternoon feeding on d 5. After completing the transition, heifers were allowed 13 d of dietary adaptation. On d 18 of each period, urinary catheters were inserted in each heifer. A 4-d total collection period occurred from d 19 to d 23 and included measurement of daily fecal

Table 4.1 Ingredient composition of diets used to transition ruminally cannulated beef heifers (n = 5) to a barley-based finishing diet prior to the start of the study. Each dietary step was fed for 4 d.

Ingredient	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Final
Barley silage	60.0	46.0	34.0	25.0	18.3	13.0	8.0
Barley grain	22.0	37.0	50.5	60.5	68.0	74.0	80.0
Canola meal	10.0	8.5	7.0	6.0	5.0	4.0	3.0
Mineral pellet	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Limestone	0.0	0.5	0.5	0.5	0.7	1.0	1.0

[1] The mineral pellet supplement was mixed with barley grain for pelleting on a DM basis ratio of 78:21, respectively. On DM basis, the mineral supplement (excluding the barley grain) contained 9.2% of calcium, 0.32% of phosphorus, 1.64% sodium, 0.28% of magnesium, 0.60% of potassium, 0.12% of sulfur, 4.9 mg/kg of cobalt, 185 mg/kg of copper, 16.6 mg/kg of iodine, 84 mg/kg of iron, 500 mg/kg of manganese, 2 mg/kg of selenium, 558 mg/kg of zinc, 40 000 IU/kg of vitamin A, 5000 IU/kg of vitamin D3, and 600 IU/kg of vitamin E. The final supplement contained 510 mg/kg of monensin (Elanco Animal Health, Greenfield, IN) on a DM basis.

Table 4.2 Ingredient inclusion and chemical composition of dietary treatments (expressed as mean ± standard deviation between periods, n = 6) fed to ruminally cannulated beef heifers (n = 5).

	Barley silage			Corn silage		
	Barley	Corn	Blend	Barley	Corn	Blend
Ingredient, % DM						
Barley silage	8.00	8.00	8.00	-	-	-
Corn silage	-	-	-	8.00	8.00	8.00
Barley grain	85.94	-	42.72	85.86	-	42.69
Corn grain	-	84.96	42.72	-	84.89	42.69
Urea	-	0.98	0.50	0.08	1.06	0.57
Mineral pellet[1]	5.56	5.56	5.56	5.56	5.56	5.56
Limestone	0.50	0.50	0.50	0.50	0.50	0.50
Chemical composition, % DM[2]						
DM, %	80.1 ± 0.56	80.1 ± 0.78	80.1 ± 0.66	82.3 ± 0.76	82.3 ± 0.83	82.3 ± 0.77
OM	94.9 ± 0.20	96.0 ± 0.29	95.5 ± 0.17	95.1 ± 0.19	96.1 ± 0.27	95.6 ± 0.07
CP	11.4 ± 0.35	11.7 ± 0.23	11.5 ± 0.08	11.5 ± 0.38	11.8 ± 0.19	11.7 ± 0.11
Starch	53.1 ± 1.17	62.0 ± 2.19	57.7 ± 1.29	53.5 ± 1.14	62.5 ± 2.07	58.0 ± 1.25
ADF	8.6 ± 0.53	6.8 ± 0.68	7.6 ± 0.50	8.4 ± 0.54	6.6 ± 0.69	7.5 ± 0.51
aNDFom	20.6 ± 1.74	13.2 ± 0.48	16.5 ± 1.31	20.4 ± 1.87	13.0 ± 0.45	16.7 ± 0.97
Ether extract	2.3 ± 0.21	4.3 ± 0.62	3.3 ± 0.29	2.2 ± 0.21	4.3 ± 0.60	3.3 ± 0.30
Ca	0.81 ± 0.01	0.78 ± 0.01	0.79 ± 0.02	0.80 ± 0.01	0.78 ± 0.01	0.79 ± 0.01
P	0.37 ± 0.02	0.36 ± 0.05	0.36 ± 0.03	0.37 ± 0.02	0.36 ± 0.05	0.37 ± 0.02
NE_m, Mcal/kg[3]	1.85	2.01	1.94	1.85	2.01	1.94
NE_g, Mcal/kg[3]	1.21	1.37	1.30	1.21	1.37	1.28

[1]The mineral pellet supplement was mixed with barley grain for pelleting on a DM basis ratio of 78:21, respectively. On DM basis, the mineral supplement (excluding the barley grain) contained 9.2% of calcium, 0.32% of phosphorus, 1.64% sodium, 0.28% of magnesium, 0.60% of potassium, 0.12% of sulfur, 4.9 mg/kg of cobalt, 185 mg/kg of copper, 16.6 mg/kg of iodine, 84 mg/kg of iron, 500 mg/kg of manganese, 2 mg/kg of selenium, 558 mg/kg of zinc, 40 000 IU/kg of vitamin A, 5000 IU/kg of vitamin D3, and 600 IU/kg of vitamin E. The final supplement contained 510 mg/kg of monensin (Elanco Animal Health, Greenfield, IN) on a DM basis.
[2]Chemical composition is expressed as means with standard deviation of the means (*n* = 6).
[3]Net energy values were calculated from feed samples using the NRC (2001) equations.

excretion, fecal pH, and daily urine excretion. Urinary catheters were removed after the final collection on d 23 and heifers were allowed 2 d of rest prior to ruminal fluid collection on d 25. Ruminal fluid sampling was initiated at 0800 h on d 25 and every 3 h thereafter until 0800 h on d 1 of the following period. BW was measured prior to feeding on 2 consecutive days at the start and end of each period (d 1 and d 25, respectively). The amount of feed provided daily was recorded and provided to target ad libitum intake with 5 to 10% residual feed daily. In addition, silage DM was measured twice weekly and the DM of all other ingredients were measured once weekly. Dietary feed ingredient inclusion was updated to reflect the most recent DM of ingredients to ensure that the as fed inclusion of ingredients accurately represented the DM formulation.

4.3.3 Ruminal Fermentation

During the sampling period, indwelling ruminal pH measurement systems (Penner et al., 2009) were placed in the ventral sac of the rumen before feeding on d 19 and removed on d 24 to ensure 96 h of data collection. The pH systems were standardized in buffers 7 and 4 at 39°C prior to insertion and after removal from the rumen and were programmed to record every 5 min. Data obtained were transformed from mV recordings to pH using beginning and end linear regressions and assuming linear drift. A ruminal pH threshold of 5.5 was used as an indicator for ruminal acidosis and the duration and area below this threshold was calculated (Penner et al., 2006).

Ruminal fluid samples were collected every 3 h from 0800 h on d 25 until 0800 h on d 1 of the following period. This resulted in a total of 8 samples representing 3-h intervals over a 24-h cycle. Digesta was collected from 3 regions of the rumen (cranial central, central, and caudal central) and strained through 2 layers of cheese cloth. Samples of the ruminal fluid (10 mL) were preserved in either 2 mL of metaphosphoric acid (25% wt/v) or 2 mL of 1% sulfuric acid for short-chain fatty acid and ammonia-N analysis, respectively. All ruminal fluid samples were sealed and stored at -20°C until further analysis. Analysis of ammonia-N was conducted using the colorimetric phenol hypochlorite method as described by Fawcett and Scott (1960). Short-chain fatty acid concentration was determined by gas chromatography (Agilent 6890 series, Agilent Technologies, Santa Clara, CA) as described by Khorasani et al. (1996).

4.3.4 Apparent Total-tract Digestibility

Feces were collected, weighed, and recorded every 6 h beginning at 0800 h on d 19 and ending at 0800 h on d 23. At each time point, feces from each heifer were thoroughly mixed and 10% of the fecal weight was collected to form a period composite that was stored at -20ºC. A subsample of feces was retained to determine the proportion and intactness of each type of cereal grain kernel in feces and the remaining composite sample of feces was then dried in forced-air oven at 55ºC to a constant weight. Samples were ground through a 1 mm screen using a Retch ZM 200 grinder (Haan, Germany). At each fecal collection time, an additional 100 g fecal sample was mixed with an equal weight of double-distilled water and pH was recorded in duplicate.

Over the 4-d sampling period, representative samples of all feed ingredients were collected daily and composited for DM and chemical analysis. Samples of refusal from the 4-d total collection were composited by heifer and also used for DM and chemical analysis. Feed and refusal samples were dried in a forced-air oven at 55ºC to a constant weight. A subsample of the grain and silage sources collected in periods 1, 3, and 5, were retained for nylon bag incubation, while the remaining concentrate samples (corn grain, barley grain, mineral pellet) were ground through a 1 mm screen using a Retch ZM 200 grinder (Haan, Germany). Barley silage and corn silage samples were ground to pass through a 1-mm screen using a hammer mill (Christie-Norris Laboratory Mill, Christie-Norris Ltd, Chelmsford, UK). All dried and ground feed, refusal, and fecal samples were analyzed for DM, OM, CP, aNDFom, ADF, starch, ether extract, calcium, and phosphorus at Cumberland Valley Analytical Services (Waynesboro, PA) as described for Study 1 with the exception of aNDFom which was estimated by combusting the final glass fiber filter and sample at 535°C for 2 h to correct for ash. Gross energy was determined using a Parr 1281 bomb calorimeter (Parr Instrument Company, Moline, Il) at the University of Saskatchewan (Saskatoon, SK, Canada).

4.3.5 Fecal Composition

Composited fecal samples collected during the total collection period were thawed and thoroughly mixed. Prior to drying, a 250-mL sub-sample was weighed, diluted in 250 mL of tap water, and screened using a 1.18-mm screen while being rinsed with tap water until only solid material remained and the water passing through the screen was clear. The material retained on the 1.18-mm screen was dried and weighed. After drying, retained material was manually sorted according to grain type (corn or barley) or fibrous material and the grain kernels were further sorted into whole or partial grain kernels. The weight of the sorted fractions was determined and recorded in order to estimate the source and amount of grain present in the feces. The whole and partial kernels of corn and barley grain and the fibrous material were calculated as a percentage of the total screened material weight after being dried.

4.3.6 Microbial N Synthesis

Total urine collection occurred from d 19 to d 23 during which urine was collected into containers containing 150 mL of HCl. Each day, a 30-mL representative sample was collected from each heifer and stored at -20°C. Collected samples were composited on an equal-volume basis and purine derivative (**PD**) concentrations were determined. Uric acid concentration was estimated using a fluorometric assay (Cayman Chemical, Ann Arbor, MI) and allantoin concentration was determined using a colorimetric method (Chen and Gomes, 1992). Measured PD concentrations were used to estimate microbial protein supply as described by (Chen and Gomes, 1992). Microbial PD absorbed (mmol/d) was calculated according to the formula:

$$\text{Microbial PD absorbed} = (\textit{Total PD excreted} - 0.385 \times \textit{BW}^{0.75}) / 0.85$$

Where total PD excreted was the sum of allantoin (mmol/d) and uric acid (mmol/d) measured in the urine and 0.85 was the assumed efficiency of PD absorption. Using microbial PD absorbed, microbial N flow (g N/d) was calculated according to the formula:

$$\text{Microbial N flow} = (\textit{PD absorbed} \times 70) / (0.116 \times 0.83 \times 1000)$$

Where PD absorbed was expressed as mmol/d, the N content of purines was estimated at 70 mg N/mmol, 0.116 was the ratio of purine N:total N for mixed rumen microbes, and 0.83 was the assumed digestibility of microbial purines (Chen and Gomes, 1992).

4.3.7 In-situ Nylon Bag Technique

Silage and grain samples retained from periods 1, 3, and 5 were used to measure ruminal degradation. All samples were previously dried in a forced air oven at 55°C prior to processing. Silage samples were ground using a hammer mill to pass through a 2-mm screen (Christy and Norris Ltd., Chelmsford, UK) and grain samples were dry-rolled. Seven grams of each sample was placed into 5 × 10 cm bags (model #R510, Ankom Technology, Macedon, NY) with a pore size of 50 μm. Bags were heat-sealed and incubated in the ventral sac of the rumen for 0, 2, 4, 8, 16, 24, 48 and 72 h with 3, 3, 3, 4, 4, 5, 5, and 6 bags as technical replicates for each sample at each time point. Period of study during which the samples were derived from was considered as the experimental unit (n = 3).

To facilitate incubations, three heifers (the same heifers as describe above) were used in two separate incubation runs to ensure that no more than 60 bags were incubated in each heifer per run. To avoid bias arising from diet, heifers were fed a common finishing diet containing (DM basis): 4% barley silage; 4% corn silage; 42.6% barley grain; 42.6% corn grain; 5.56% mineral pellet; 0.67% urea; and 0.5% limestone for at least 7 d prior to incubations. Bags were inserted into the rumen using a sequential-in, all-out approach (NRC, 2001) as detailed by Rosser et al., (2013). Upon removal, bags were washed 5 times in cold water and then placed in a forced-air oven at 55°C for 48 h. Dried bags were subsequently weighed and all sample remaining in bags were composited by ingredient replication, period, and incubation time. Composited time point samples were then analyzed for DM, CP, aNDFom and starch content at Cumberland Valley Analytical Services (Waynesboro, PA) as described above.

4.3.8 Statistical Analysis

Data were analysed as an incomplete Latin square using the mixed model of SAS (SAS version 9.4, SAS Institute, Cary, NC) with fixed effects of silage type (**S**), cereal grain type (**G**), and the silage × cereal grain interaction (**S × G**) with the random effects of heifer and period. Prior to being analysed, all data and their residuals were tested for normality, and data that were not normally distributed were corrected. Correction required that mean, minimum, and maximum pH, area that pH was < 5.5, ammonia-N, and isovalerate data be normalized using log transformation, propionate was reflected, and the inverse of valerate was used. Means and SEM were reverse transformed for presentation in tables. Short-chain fatty acid and ammonia-N concentrations were analyzed with time as a repeated measure using a compound symmetry covariance structure as it yielded the lowest Akaike's and Bayesian Information Criterion values. For the treatment sequence where a heifer was replaced it was assumed that effect of heifer would not be affected.

For fecal kernel data, data were analysed using the mixed model of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) with the fixed effect of silage source, grain source, and the 2-way interaction and heifer and period as random effects. For variables where all observations within a treatment were equal to 0, the treatment was excluded from analysis for that specific variable and kernel appearance was marked as not present (NP) instead. This occurred when it was not possible to have either corn or barley in the feces (e.g., diets based on CS with CG could not have BG in the feces). Data were analysed using the GLIMMIX procedure of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) with binominal error structure and logit data transformation.

In situ rumen degradation kinetics were used to calculate the soluble fraction (S, %), potentially degradable fraction (D, %), undegradable fraction (U, %) and rate of degradation (Kd, %/hr) of DM, CP, aNDFom (for silages) and starch of feed samples. Data were analysed using the non-linear (NLIN) procedure of SAS (SAS version 9.4, SAS Institute, Inc. 2002) based on a modified first-order kinetics and iterative least-squares regression (Ørskov and McDonald, 1979). Feed fractions and rate data were then analysed using the Mixed Model (SAS version 9.4, SAS Institute, Inc. 2002) to obtain least squared means. Due to low digestibility of DM, CP and aNDFom for the silage sources, the data did not fit the kinetic model. As a result, 24, 48 and 72-h digestibility values were reported instead. The effective degradability (**ED**) of DM, CP, and starch were calculated for grain sources assuming a passage rate (Kp) of 6%/h (Ørskov and McDonald, 1979). For all analysis, significance was declared at a P value < 0.05. When the effect of grain type was significant, or if the interaction between silage and grain source was significant, means were separated using a Students *t*-test.

4.4 Results

4.4.1 Dietary Treatments

As intended with the formulation strategy, starch and ether extract concentrations numerically increased and aNDFom decreased with increasing corn grain inclusion (Table 4.2). As a result of greater starch and ether extract, the net energy contents calculated using chemical composition were greatest for CG diets, intermediate for BCG, and least for BG.

4.4.2 Dry Matter Intake and Ruminal Fermentation

There were no effects of S, G, or their interaction on DMI ($P \geq 0.19$, Table 4.3). Starting and ending BW were also not affected by dietary treatment. For ruminal pH, there was

Table 4.3 Effect of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn grain on DMI, BW, and ruminal fermentation when fed to ruminally cannulated beef heifers (n = 5) .

	Barley silage			Corn silage				*P*-values		
	Barley	Corn	Blend	Barley	Corn	Blend	SEM[1]	Silage	Grain	S × G[2]
DMI, kg/d	8.55	8.69	9.53	9.51	9.48	9.32	0.57	0.19	0.65	0.40
Start weight, kg	475	479	482	456	459	472	29.9	0.08	0.54	0.89
End weight, kg	508	508	518	493	496	510	28.6	0.20	0.43	0.94
Ruminal pH										
Mean pH	6.35	6.14	6.00	6.06	5.94	6.16	0.15	0.16	0.32	0.10
Minimum pH	5.68$_{y}$	5.55$_{yz}$	5.32$_{z}$	5.39$_{yz}$	5.33$_{yz}$	5.63$_{y}$	0.16	0.66	0.81	0.03
Maximum pH	7.04$_{a}$	6.78$_{b}$	6.76$_{ab}$	6.77$_{a}$	6.52$_{b}$	6.71$_{ab}$	0.12	0.02	0.03	0.31
Duration < 5.5, min/d	77.8	132.8	189.5	125.3	231.5	85.0	74.62	0.77	0.40	0.21
Area < 5.5, (pH × min)/d	10.6$_{z}$	14.4$_{yz}$	39.2$_{y}$	15.7$_{y}$	54.3$_{y}$	13.0$_{yz}$	16.04	0.28	0.43	0.03
Rumen Fermentation										
Total SCFA, m*M* [3]	123.5$_{b}$	122.5$_{b}$	130.9$_{a}$	129.4$_{b}$	128.3$_{b}$	139.5$_{a}$	5.86	< 0.01	< 0.01	0.88
SCFA Proportions, mol/100 mol[3]										
Acetate	46.83$_{x}$	47.14$_{x}$	44.79$_{z}$	44.11$_{z}$	44.49$_{z}$	45.78$_{y}$	0.91	< 0.01	0.33	< 0.01
Propionate	40.88$_{z}$	41.02$_{z}$	43.56$_{z}$	46.51$_{x}$	42.17$_{z}$	44.81$_{y}$	1.58	< 0.01	< 0.01	< 0.01
Butyrate	8.63$_{wx}$	8.31$_{wx}$	7.57$_{xy}$	5.49$_{z}$	9.10$_{w}$	6.12$_{yz}$	0.95	< 0.01	< 0.01	< 0.01
Isobutyrate	0.70$_{y}$	0.55$_{z}$	0.55$_{z}$	0.59$_{z}$	0.58$_{z}$	0.53$_{z}$	0.06	0.13	< 0.01	0.05
Isolvalerate	1.39	1.42	1.18	0.97	1.07	0.91	0.14	< 0.01	0.29	0.66
Valerate	1.15$_{z}$	1.14$_{yz}$	1.74$_{x}$	1.43$_{x}$	1.53$_{xy}$	1.19$_{z}$	0.18	0.11	0.71	< 0.01
NH_3-N, mg/dL [3]	2.20$_{b}$	2.97$_{a}$	1.93$_{b}$	2.39$_{b}$	3.50$_{a}$	3.11$_{b}$	0.48	0.02	< 0.01	0.23

[a,b,c]Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

[x,y,z] Values within a row with uncommon letters were identified as having a S × G interaction ($P < 0.05$).

[1]Greatest SEM was reported.

[2]S × G = silage by grain interaction.

[3]n = 240 for total SCFA. Outliers were removed for acetate, propionate, butyrate and isobutyrate, n = 227, for isovalerate n = 225, for valerate n = 221 and for NH_3-N n = 235.

effect of silage or grain source on mean pH values ($P > 0.09$). A S × G interaction was detected for minimum pH ($P = 0.03$) with BS-BG and CS-BCG achieving the highest minimum pH values while BS-BCG had the lowest, and the other combinations of silage and grain sources were intermediate but not different from all other treatments. Maximum pH was the highest for BG, lowest for CG, and intermediate but not different from other grain sources for BCG (G, $P = 0.03$). Maximum pH was higher for BS than CS (S, $P = 0.02$). The duration that pH was < 5.5 was not affected by G, S, or their interaction ($P > 0.05$). But, the area that pH < 5.5 was affected by a S × G interaction ($P = 0.03$) where area was greatest for CS-CG, BS-BCG, and CS-BG, intermediate but not different for BS-CG and CS-BCG, and least for BS-BG.

Total SCFA concentration was greater for CS than BS (S, $P < 0.01$) and greater for BCG relative to BG and CG (G, $P < 0.01$). The molar proportion of acetate was greatest (S × G, $P < 0.01$) for BS-CG and BS-BG, intermediate for CS-BCG, and least for CS-BG, CS-CG, and BS-BCG. Propionate concentration (mol/100 mol) was greatest for CS-BG, intermediate for CS-BCG, and least for BS-BG, BS-CG, BS-BCG, and CS-CG (S × G, $P < 0.01$). The molar proportion of butyrate was greatest for CS-CG and least for CS-BG (S × G, $P < 0.01$). Isobutyrate were greater for BS-BG than for CS-BG, BS-CG, BS-BCG, CS-CG and CS-BCG (S × G, $P = 0.05$) while the molar proportion of isovalerate was greater for BS than CS (S, $P < 0.01$). The molar proportion of valerate was greatest in rumen fluid from heifers fed BS-BCG and CS-BG, and least when fed BS-BG and CS-BCG (S × G, $P < 0.01$). While the concentrations of ammonia-N were low, the concentration was greater for CS than BS (S, $P = 0.02$), and was greater when fed CG than BG or BCG (G, $P < 0.01$). For ammonia-N, there was a time × grain interaction ($P < 0.01$) in which concentrations were greatest for BCG at 0800 h, least for BG at 1400 h, and generally intermediate and not different for other time points.

4.4.3 Apparent Total-tract Digestibility

There was no effect of S or S × G interactions for apparent total-tract digestibility, gross energy digestibility, or digestible energy concentration (Table 4.4). DM, OM, and aNDFom digestibility were greater for BG than CG and BCG (G, $P \leq 0.04$). Digestibility of ADF was greater for CG than BG and BCG (G, $P < 0.01$). Starch digestibility was greatest for BG, intermediate for BCG, and least for CG (G, $P < 0.01$). Ether extract digestibility did not differ among treatments. Gross energy digestibility was greater for BG than for CG and BCG (G, $P = 0.01$). Digestible

Table 4.4 Effect of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn to ruminally cannulated beef heifers (n = 5) on apparent nutrient total-tract digestibility gross energy digestibility, and dietary digestible energy content.

	Barley silage			Corn silage				*P*-values		
	Barley	Corn	Blend	Barley	Corn	Blend	SEM	Silage	Grain	S × G[1]
Apparent total-tract digestibility, % DM basis										
DM	77.4[a]	75.1[b]	76.1[b]	78.7[a]	75.2[b]	74.1[b]	1.90	0.87	0.035	0.37
OM	78.9[a]	76.1[b]	77.4[b]	80.0[a]	76.2[b]	75.2[b]	1.86	0.74	0.016	0.37
ADF	27.1[b]	49.6[a]	33.6[b]	31.6[b]	54.2[a]	37.0[b]	4.26	0.16	< 0.001	0.98
aNDFom[2]	47.0[a]	42.1[b]	39.5[b]	49.8[a]	42.8[b]	42.5[b]	3.35	0.32	0.026	0.89
Starch	97.7[a]	90.2[c]	93.4[b]	97.5[a]	90.2[c]	92.0[b]	1.45	0.46	< 0.001	0.69
Ether extract	77.5	80.5	78.3	76.7	77.3	74.5	3.71	0.18	0.53	0.78
GE	77.1[a]	74.0[b]	75.2[b]	78.3[a]	73.9[b]	73.2[b]	1.93	0.78	0.011	0.39
DE, Mcal/kg DM	3.42[a]	3.32[b]	3.34[b]	3.47[a]	3.32[b]	3.26[b]	0.09	0.79	0.029	0.46

[a,b,c]Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

[1]S × G = silage by grain interaction.

[2]NDF measured using alpha amylase and sodium sulfite corrected for ash content.

energy concentration (Mcal/kg) was greater for BG than for CG and BCG (G, $P = 0.03$).

4.4.4 Nitrogen Balance

As diets were similar in CP content and DMI did not differ, N intake did not differ among S or G sources (Table 4.5). Fecal pH was greater for BG than CG and BCG (G, $P < 0.01$), but did not differ by S source. Additionally, there were no effects of S, G, or the S × G interaction dietary treatment on urine output or predicted bacterial N supply.

Both fecal N excretion (g/d) and total N excretion (g/d) were greater for CS than BS (S, $P \leq 0.04$), and were greatest for BCG, intermediate but not different for CG, and least for BG (G, $P \leq 0.02$). Though urinary N excretion (g/d) was not affected by G, S, or the G × S interaction, urine excretion as a % of N intake was greatest for CS-BCG and least for CS-BG (S × G, $P = 0.01$). Fecal N excretion as a % of N intake was not affected by dietary treatment. Total N excretion (% of N intake) was greatest for CS-BCG and BS-BG, intermediate but not different for CS-CG, CS-CG and BS-BCG, and least for CS-BG (S × G, $P = 0.03$).

Apparent N digestion in g/d and as a % of N intake were not affected by dietary treatment ($P > 0.05$). N retention in g/d and as a % of intake were greatest for CS-BG, intermediate but not different for BS-CG, BS-BCG and CS-CG, and least for BS-BG and CS-BCG (S × G, $P \leq 0.03$).

4.4.5 Fecal Composition

Fecal output did not differ between S sources but was greater for BCG and CG compared to BG (G, $P = 0.02$; Table 4.6). Fecal DM and starch content were greatest for CG, intermediate for BCG, and least for BG (G, $P < 0.01$). Wet weight of the 250 mL fecal samples was greatest for BS-CG, intermediate for CS-BCG, and least for BS-BCG and CS-BG (S × G, $P = 0.02$). The weight of material retained on the 1.18-mm sieve after screening was greatest for CG, intermediate for BCG, and least for BG treatments (G, $P < 0.01$). Appearance of whole barley kernels in the feces was greatest for CS-BG and least for BS-CG (S × G, $P < 0.01$). Partial barley kernels and whole corn kernels in feces were not affected by S, G, or their interaction. Partial corn kernel appearance was greatest for CG diets, intermediate for BCG diets and least for BG diets, (G, $P < 0.01$). The proportion of fibre remaining was greatest for BG diets, intermediate for BCG diets, and least for CG diets (G, $P < 0.01$).

Table 4.5 Effect of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn grain on nitrogen balance and estimated microbial protein supply in ruminally cannulated beef heifers (n = 5).

	Barley silage			Corn silage				*P*-values		
	Barley	Corn	Blend	Barley	Corn	Blend	SEM[1]	Silage	Grain	S × G[2]
N intake, g/d	156.7	160.5	176.9	177.9	180.4	174.0	10.76	0.09	0.64	0.31
Fecal pH	6.76[a]	6.16[b]	6.40[b]	6.90[a]	6.08[b]	6.27[b]	0.15	0.79	< 0.001	0.37
Urine output, kg/d	9.81	7.46	8.53	8.62	9.69	9.23	1.17	0.43	0.77	0.18
Bacterial N production, g/d	75.2	63.2	73.8	63.3	77.6	79.3	12.66	0.78	0.79	0.51
N excretion, g/d										
Fecal	44.1[b]	48.1[ab]	54.9[a]	49.8[b]	54.7[ab]	55.5[a]	4.05	0.041	0.011	0.41
Urine	85.0	79.4	84.3	79.4	94.4	96.8	6.37	0.057	0.19	0.065
Total	129.0[b]	127.6[ab]	139.7[a]	129.0[b]	149.2[ab]	151.9[a]	8.28	0.019	0.020	0.16
N excretion, % of N intake										
Fecal	29.0	30.1	30.9	28.1	30.2	32.1	2.17	0.93	0.17	0.77
Urine	54.6[xy]	50.9[xyz]	47.6[yz]	44.5[z]	51.9[xyz]	56.4[x]	3.40	0.98	0.67	0.011
Total	83.5[y]	81.1[yz]	78.6[yz]	72.5[z]	82.1[yz]	88.4[y]	4.17	0.99	0.33	0.030
Apparent N digestion										
g/d	112.8	112.0	122.1	128.2	125.9	118.4	9.07	0.17	0.97	0.37
% of N intake	71.0	69.9	69.1	71.9	69.8	67.9	2.70	0.93	0.17	0.77
N retained										
g/d	28.6[z]	31.6[yz]	38.1[yz]	49.0[y]	31.8[yz]	21.1[z]	7.65	0.82	0.36	0.033
% of N intake	16.5[z]	18.9[yz]	21.4[yz]	27.5[y]	17.9[yz]	11.6[z]	4.17	0.99	0.33	0.030

[a,b,c]Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

[x,y,z] Values within a row with uncommon letters were identified as having a S × G interaction ($P < 0.05$).

[1]Greatest SEM was reported.

[2]S × G = silage by grain interaction.

Table 4.6 Effects of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn grain on fecal characteristics and composition of solids retained on a 1.18 mm sieve of a fecal composite collected from ruminally cannulated beef heifers (n = 5).

	Barley silage			Corn silage				*P*-values		
	Barley	Corn	Blend	Barley	Corn	Blend	SEM[1]	Silage	Grain	S × G[2]
Fecal output, kg DM/d	1.90_{b}	2.18_{a}	2.29_{a}	2.03_{b}	2.36_{a}	2.38_{a}	0.21	0.20	0.016	0.94
Fecal DM, %	22.12_{c}	28.01_{a}	26.78_{b}	23.19_{c}	28.32_{a}	25.80_{b}	1.26	0.80	< 0.001	0.48
Fecal starch, % DM	4.8_{c}	23.3_{a}	16.1_{b}	6.1_{c}	23.1_{a}	17.6_{b}	2.22	0.39	< 0.001	0.76
Wet fecal weight, g/250 mL	248.3_{yz}	265.2_{x}	247.5_{z}	239.9_{z}	252.9_{xyz}	261.4_{y}	6.73	0.54	0.011	0.020
Total retained, g	18.3_{c}	42.9_{a}	32.3_{b}	23.3_{c}	42.3_{a}	32.9_{b}	4.89	0.50	< 0.001	0.61
Whole barley, % retained	16.50_{b}	1.80_{d}	14.39_{b}	24.16_{a}	NP	8.45_{c}	1.91	0.64	< 0.001	< 0.001
Partial barley, % retained	3.22	NP	0.61	1.30	NP	0.60	0.82	0.26	0.061	0.26
Whole corn, % retained	NP	0.33	0.55	NP	1.06	0.55	0.46	0.36	0.90	0.36
Partial corn, % retained	NP	58.71_{a}	28.72_{b}	0.69_{c}	58.50_{a}	36.96_{b}	4.21	0.38	< 0.001	0.35
Fibre, % retained	80.28_{a}	39.16_{c}	55.72_{b}	73.85_{a}	40.44_{c}	53.88_{b}	6.14	0.64	< 0.001	0.82

[a,b,c] Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).
[x,y,z] Values within a row with uncommon letters were identified as having a S × G interaction ($P < 0.05$).
NP = Not present
[1]Greatest SEM was reported.
[2]S × G = silage by grain interaction.

4.4.6 In-situ Nylon Bag Kinetics and Digestibility

The degradation rate of DM, CP, and starch were greater for BG than CG ($P < 0.01$; Table 4.7). There were no differences in the soluble fractions for DM, CP, or starch among grain sources. But, CG had greater degradable fractions and less undegradable fractions of DM, CP, and starch than BG ($P < 0.03$). Effective degradability of DM, CP, and starch were greater for BG than CG ($P \leq 0.01$).

After 24 h of ruminal incubation, DM digestibility was greater for CS than BS ($P = 0.01$; Table 4.8), but there were no differences in DM digestibility at 48 or 72 h. There were no differences in digestibility of CP or aNDFom between silages at any of the three time points measured. However, starch digestibility after 24, 48, and 72 h was greater for CS than BS ($P < 0.04$).

4.5 Discussion

The objective of the current study was to evaluate the effects and possible interactions of silage type (corn vs. barley) and cereal grain type (corn vs. barley vs. blend) on DMI, ruminal fermentation, total-tract digestibility, fecal pH, and microbial protein supply in finishing beef heifers. Although we hypothesized that diets containing a blend of BG and CG would improve starch and protein degradation and ultimately result in greater total-tract digestibility, and improved microbial protein production, our results do not support the hypothesis.

Positive associative effects have been observed in a number of studies when feeding a combination of grain sources to finishing cattle (Stock et al., 1987b). However, the combination of dry-rolled CG and dry-rolled BG has not been previously examined. Additionally, there are a limited number of studies comparing the effects that combining grain sources has on ruminal fermentation, nitrogen balance, or total-tract digestibility that prompt the additive improvements in performance observed in feedlot studies. For studies evaluating dry-rolled grains, Kreikemeier et al. (1987) reported that including dry-rolled wheat within dry-rolled corn-based diets improved ADG and feed efficiency compared to feeding either grain source independently. In this instance, wheat had 35% greater rate of starch digestion when measured *in vivo* than dry-rolled corn (Kreikemeier et al., 1987). It has been suggested that the magnitude of improvement is dependent upon the grain sources being fed, where blends of grains that vary greatly in rate and extent of

Table 4.7 Rate of *in situ* degradation, soluble, degradable and undegradable fractions as determined by ruminal nylon bag incubation of grain sources collected during periods 1, 3, and 5 of the study.

Parameter[1]	Barley grain	Corn grain	SEM[2]	*P*-values
DM				
Kd, %/h	15.62[a]	2.92[b]	1.34	< 0.01
Soluble, %	3.38	4.05	0.80	0.59
Degradable, %	72.28[b]	83.78[a]	1.48	< 0.01
Undegradable, %	24.34[a]	12.17[b]	2.21	0.02
ED, %	55.38[a]	31.45[b]	2.82	< 0.01
CP				
Kd, %/h	9.29[a]	1.53[b]	0.52	< 0.01
Soluble, %	5.00	6.53	1.80	0.58
Degradable, %	75.89[b]	93.47[a]	1.58	< 0.01
Undegradable, %	19.11[a]	0.00[b]	1.94	< 0.01
ED, %	51.02[a]	25.48[b]	2.82	< 0.01
Starch				
Kd, %/h	16.23[a]	2.99[b]	1.55	< 0.01
Soluble, %	3.23	1.54	1.28	0.40
Degradable, %	85.51[b]	95.41[a]	2.14	0.03
Undegradable, %	11.26[a]	3.05[b]	2.03	0.05
ED, %	65.30[a]	33.22[b]	2.87	< 0.01

[a,b,c]Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

[1]Kd = rate of degradation fraction, ED = effective degradability.

[2]Greatest SEM was reported.

Table 4.8 *In situ* digestibility of DM, CP, aNDFom, and starch for corn silage and barley silage samples collected during periods 1, 3, and 5 of the study.

Parameter	Barley silage	Corn silage	SEM	*P*-values
Digestibility, %				
DM				
24 hr	1.42[b]	14.13[a]	0.84	< 0.01
48 hr	14.67	18.67	1.76	0.18
72 hr	18.75	22.44	1.56	0.17
CP				
24 hr	0.00	2.57	1.70	0.34
48 hr	2.31	3.89	2.27	0.65
72 hr	4.70	12.82	3.99	0.22
aNDFom				
24 hr	3.55	2.70	1.64	0.73
48 hr	8.70	6.93	3.31	0.72
72 hr	11.48	10.04	2.13	0.66
Starch				
24 hr	81.57[b]	91.80[a]	0.98	< 0.01
48 hr	91.19[b]	95.82[a]	1.04	0.03
72 hr	94.47[b]	96.47[a]	0.42	0.03

[a,b,c]Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

ruminal degradation produce the greatest benefits. *In situ* measurements in the present study, found that the kd and effective degradability of starch in barley was more than 5 and nearly 2 times greater than for corn, respectively. The observed differences in the rate of starch digestion and effective degradability suggest that the magnitude of difference in fermentability between the two grain sources should have been adequate to detect additive effects with regards to digestibility or ruminal fermentation, yet none were observed.

Another theory to explain additive effects as a result of grain mixtures has been through a reduced risk of ruminal acidosis. In fact, Huck et al. (1998) suggested that performance improvements observed when combining differing sources of grain in finishing diets may be a result of replacing a portion of rapidly fermentable grain with a more slowly fermentable source thereby reducing the risk of ruminal acidosis (Axe et al., 1987; Kreikemeier et al., 1987) and avoiding a decrease in DMI due to digestive upsets. These findings are supported by Bock et al. (1991) who in contrast, fed diets composed of two rapidly fermented grain sources, high-moisture corn with either dry-rolled or steam-rolled wheat, and still observed that addition of 33 to 25% wheat in high-moisture corn based diets slowed rate of ruminal starch digestion, potentially reducing risk of ruminal acidosis. However, in the current study we did not observe differences in DMI and minimum pH was greatest for BS-BG and CS-BCG and highest for BG, while mean pH was only numerically greater for BS-BG. The general trend for pH being greater for BG diets despite the greater *in situ* ruminal degradation rate and effective degradability of DM, CP, and starch for BG compared to CG suggests that greater supply of dietary starch content of CG and greater degradable fractions may have sustained fermentation over a longer duration. This hypothesis is supported by the reduction in ruminal pH in diets with CG relative to BG. In contrast, the rapid degradability of BG may have initially led to an increase in SCFA production, but with a high effective degradability and rapid rates of fermentation, there may have been adequate time to facilitate recovery of ruminal pH, as demonstrated by reduced area below pH 5.5, and greater maximum and minimum pH values observed for BG treatments. These results and proposed mechanisms contrast the theory posed by Huck et al. (1998) in that we observed that the more rapidly degradable source of starch, in this case BG, actually resulted in greater maximum pH: a finding that is counterintuitive (Herrera-Saldana et al., 1990).

While we cannot confirm why only limited additive effects occurred, it is possible that the relatively low processing severity for dry-rolled corn or a high passage rate of dry-rolled corn out of the rumen resulted in insufficient ruminal fermentation when combined with dry-rolled barley. Unfortunately, we did not assess ruminal digestibility of starch nor did we measure passage rates to confirm this speculation; however, the high fecal starch values observed partially support the statement. Nonetheless, there is sufficient data to support that feeding cereal grains of differing sources may stimulate additive effects by altering rate or extent of starch digestion and modifying ruminal fermentation of nutrients. However, the combination of dry-rolled corn and dry-rolled barley did not seem to induce additive effects as the blended grain treatments in the currently study largely performed intermediately to the single grain source treatments.

Given that lowest minimum pH was observed with the BS-BCG treatment, and that lower pH is generally associated with greater concentration of SCFA (Aschenbach et al., 2011) it is not surprising that total SCFA concentrations were greatest for BCG. SCFA concentrations were also greater for CS than BS. It should be recognized that greater SCFA concentrations can result from greater production, reduced absorption, or altered ruminal volume: factors we could not measure with the current experimental design. When reported as a molar proportion, propionate was greatest for CS-BG. Since propionate is the major glucogenic precursor in ruminants (Allen et al., 2009), increased concentration of propionate is favourable as it is associated with increased energetic efficiency and improved performance. Additionally, the increased concentrations of ammonia-N for CG and CS treatments is likely a reflection of greater urea addition to balance CP for these treatments.

Total-tract digestibility of DM, OM, aNDFom, starch, and gross energy as well as the dietary digestible energy content were greatest for BG diets. Numerous previous studies have reported greater digestibility for dry-rolled BG than CG (Study 1; Boss and Bowman, 1996). That said, we also observed that BG had a larger fraction of undegradable DM, CP, and starch when measured *in situ*. However, fecal starch for BG treatments was lower than expected given the relatively large amount of whole barley kernels in the feces of heifers fed BG. Given the higher PI of CG and lower starch digestibility, a large amount of fractured CG kernels were present in the feces of heifers fed CG. Likewise, the higher PI and use of dry-rolling for CG may not have promoted digestibility of CG as it is known that dry-rolling does very little to disrupt the structure of the starch and protein matrix of CG and is not an optimal processing method to maximize starch digestibility (Owens et al., 1997; Zinn et al., 2011), as demonstrated by high fecal starch content and reduced digestibility for CG treatments.

For silage sources, *in situ* digestibility of nutrients was very low. It has been well documented that the rumen microbiome is altered based on diet composition (Petri et al., 2012; Petri et al., 2013; Khafipour et al., 2016) and it has been speculated that the shift in the microbiome may reduce ruminal NDF digestibility (Russell and Wilson, 1996). These data support the concept that NDF contributes little to the dietary energy supply in finishing diets (Joy et al., 2015). The limited degradation of NDF for silage in finishing diets, greater starch digestion for CS than BS, and greater DMI and ADG for steers finished with CS than BS in Study 1 further supports that higher levels of starch in CS may have stimulated the positive responses observed. The greater digestibility of starch in CS likely reflects the use of a kernel processor at harvest as compared to no kernel processing with BS.

It is possible that when combing sources of starch that are rapidly digested (BG) with sources that are slowly digested (CG) there may be a shift in site of starch digestion from the rumen to the small and large intestine that may improve efficiency of nutrient utilization. Owens et al. (1986) estimated that starch digested in the small intestine may provide up to 42% more energy than when fermented in the rumen. However, data in the present study suggest that with the dry-rolling, CG utilization was lower than for BG using similar processing methods. For example, CG had lower effective degradability than barley, had lesser total-tract starch digestion, greater fecal starch, and greater excretion of partial kernels in the feces. While the lower fecal pH observed for CG and BCG diets in the current study suggest an increase in post-ruminal starch digestion, no improvements in growth or carcass quality were observed in Study 1 that would suggest a benefit to altering the site of starch digestion. It is possible that the large amount of starch reaching the small intestine may have exceeded the capabilities for intestinal starch digestion (Huntington et al., 2006), thus the benefits to post-ruminal starch digestion were not observed and could not compensate for the excess undigested starch leaving the rumen.

Altering the rate and extent of starch digestion in the rumen may also influence N use efficiency and microbial protein synthesis (Streeter et al., 1989; Axe et al., 1987). In fact, Huck et al. (1998) suggested that altered N use efficiency may partially explain the positive associative effects observed when cereal grains with markedly different rumen fermentation are combined in a diet. Although, rates of ruminal starch digestion differed between the CG and BG, we did not observe any differences in microbial protein production. However, N retention, in g/d and as a % of N intake, was greatest for the CS-BG treatment; the only evidence of an associative effect observed in the present study. Kohn et al., (2005) reported that 26 g of N retained was required per kg of ADG when holding the composition of tissue accretion constant. Based on the estimate of Kohn et al. (2005), estimates of ADG required to achieve the N retention values observed in the present study were 1.89, 1.39, 1.27, 1.21, 1.04, and 0.90 kg/d for CS-BG, BS-BCG, BS-CG, CS-CG, BS-BG, and CS-BCG, respectively. On average, these values were 9% lower than the gains observed during the study. Since actual gains include skeletal weight, adipose tissue, and muscle, it is possible that difference between actual gain and that predicted with N can be explained by accretion of components that do not contain N. While BW gains in Latin squares are often criticized due to the high variability in BW measurements and the relatively short periods, we observed similar rates of gain in Study 1 when evaluating growth performance.

Previous studies have demonstrated that combining grain sources with varying rates of ruminal degradability may improve performance through various mechanisms including reducing ruminal acidosis, shifting site of starch digestion, altering N digestion, as well as improving efficiency of microbial protein production. Though it was hypothesized that feeding a combination of corn and barley grains would act through such mechanisms to result in improved total-tract nutrient utilization and improved microbial protein production, there were few positive associative effects observed. Results of the present study confirm that when comparing dry-rolled corn and barley, barley has a greater rate of digestion, increased total-tract digestibility, and may not reduce ruminal pH.

5.0 GENERAL DISCUSSION

5.1 Regional Considerations for Corn Production

Western Canada is one of a few geographical regions where production of corn and barley can be financially beneficial. Barley grain (**BG**) and barley silage (**BS**) have been the staple feed sources of the western Canadian cattle feeding industry for many years. However, there is an increasing number of short-season hybrid corn varieties available that are capable of reaching maturity at <2200 corn heat units (**CHU**). Despite this, there are few studies conducted to date in western Canada comparing new corn varieties to barley. Long term changes in climate patterns indicate increases in growing season precipitation for the prairie regions and a significant positive trend in CHU accumulation for southern-most regions (Nadler and Bullock, 2011). More recently, CHU maps from Agriculture and Agri-Food Canada (2019) illustrate that from 2015 to 2018, that south-eastern regions of Alberta, southern Saskatchewan, and south-western Manitoba accumulated greater than 2500 CHU from April 1 to October 31 each year, with even larger areas achieving > 2200 CHU (Figures 5.1, 5.2, 5.3, and 5.4). As such, the prairie regions are becoming increasingly suitable for corn production when combined with the advancing short-season corn technology, giving producers the option to produce corn as opposed to barley as grain or silage sources.

The short growing season and drought tolerance of barley has contributed largely to its adoption as a major feed source in western Canada. Composition of barley can be altered greatly by geographical, genetic, environmental, and agronomic factors, resulting in large variation among sources (Khorasani et al., 2000). Often, variety selection for silage or grain production is based on yield or agronomic characteristics rather than nutritional value. A number of studies have been conducted demonstrating that there are significant differences in chemical composition of BS and BG between varieties (Boss and Bowman, 1996b; Khorasani et al., 2000; Nair et al., 2016). Differences in nutritional characteristics such as greater neutral detergent fibre digestibility (**NDFD**), lower indigestible neutral detergent fibre content (**INDF**), or more rapid rate and greater extent of nutrient disappearance have been associated with greater grain or forage quality (Boss and Bowman, 1996b; Nair et al., 2016; Nair et al., 2018). For BG, selection for these traits among barley varieties has been demonstrated to result in greater dry matter intake (**DMI**), average daily gain (**ADG**), and carcass quality for finishing steers compared to other varieties (Boss and Bowman, 1996a). Nair et al. (2017) noted differences for BS in DMI, ADG, and gain to feed (**G:F**)

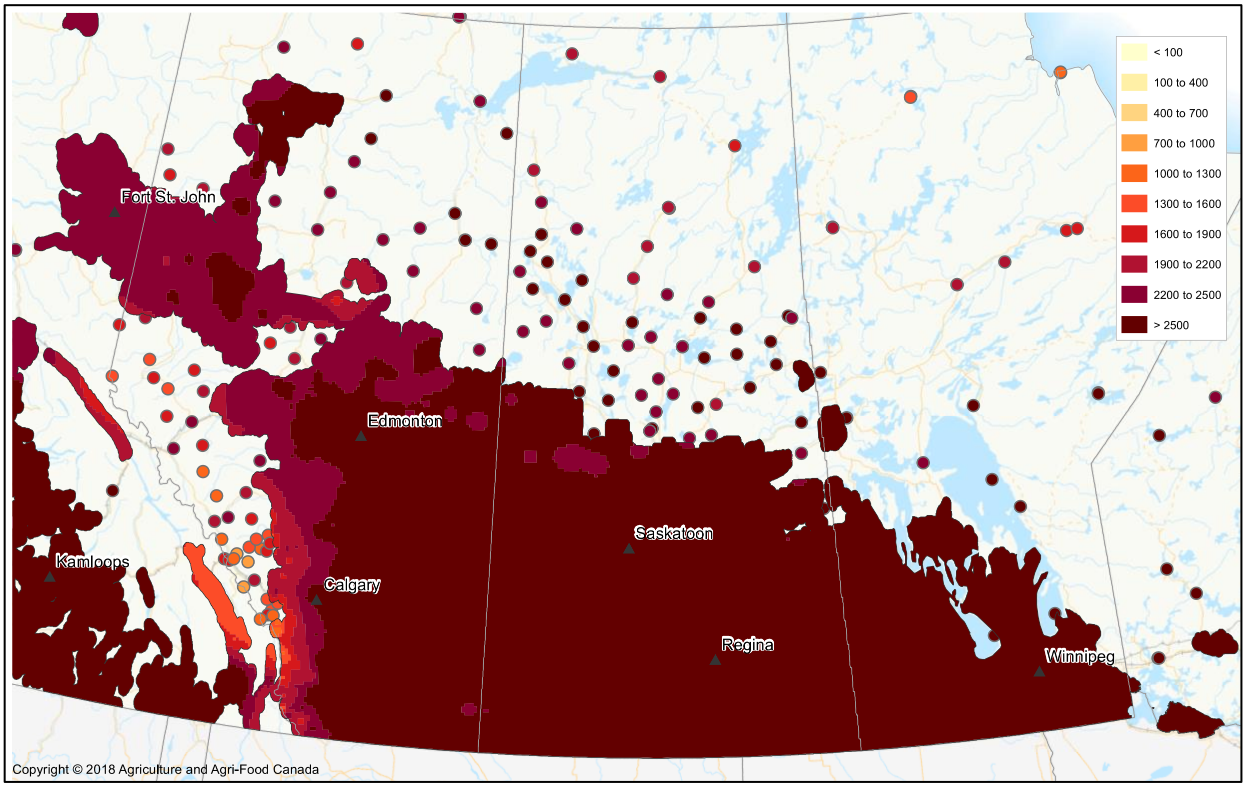

Figure 5.1 Map depicting corn heat units accumulated in western Canada from April 1 to October 31, 2015 (Agriculture and Agri-Food Canada, 2019)

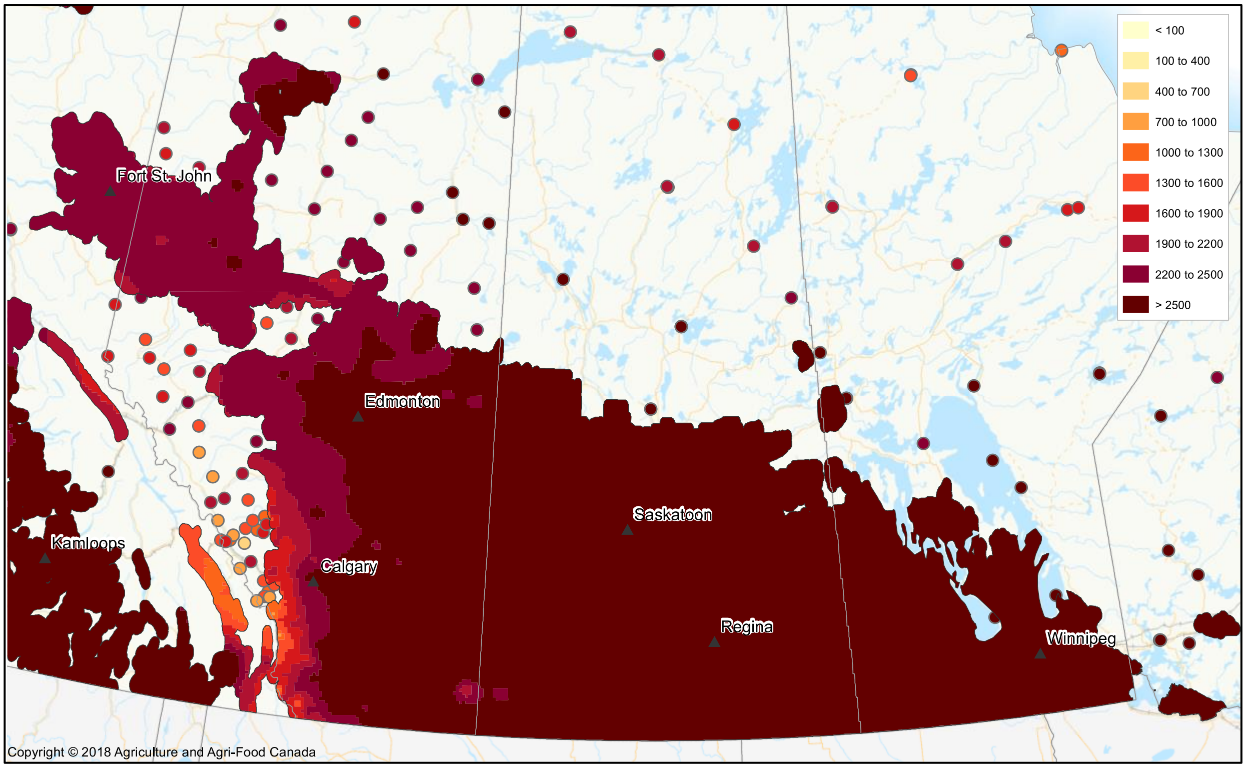

Figure 5.2 Map depicting corn heat units accumulated in western Canada from April 1 to October 31, 2016 (Agriculture and Agri-Food Canada, 2019)

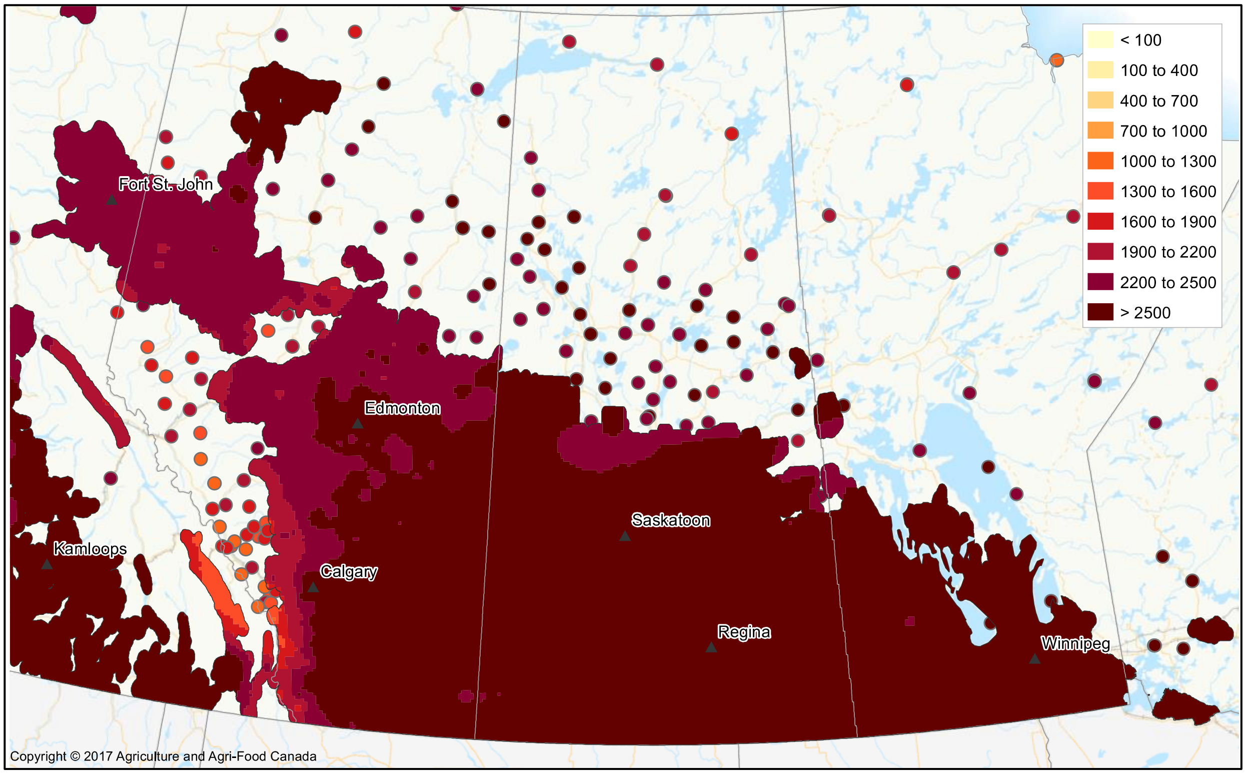

Figure 5.3 Map depicting corn heat units accumulated in western Canada from April 1 to October 31, 2017 (Agriculture and Agri-Food Canada, 2019)

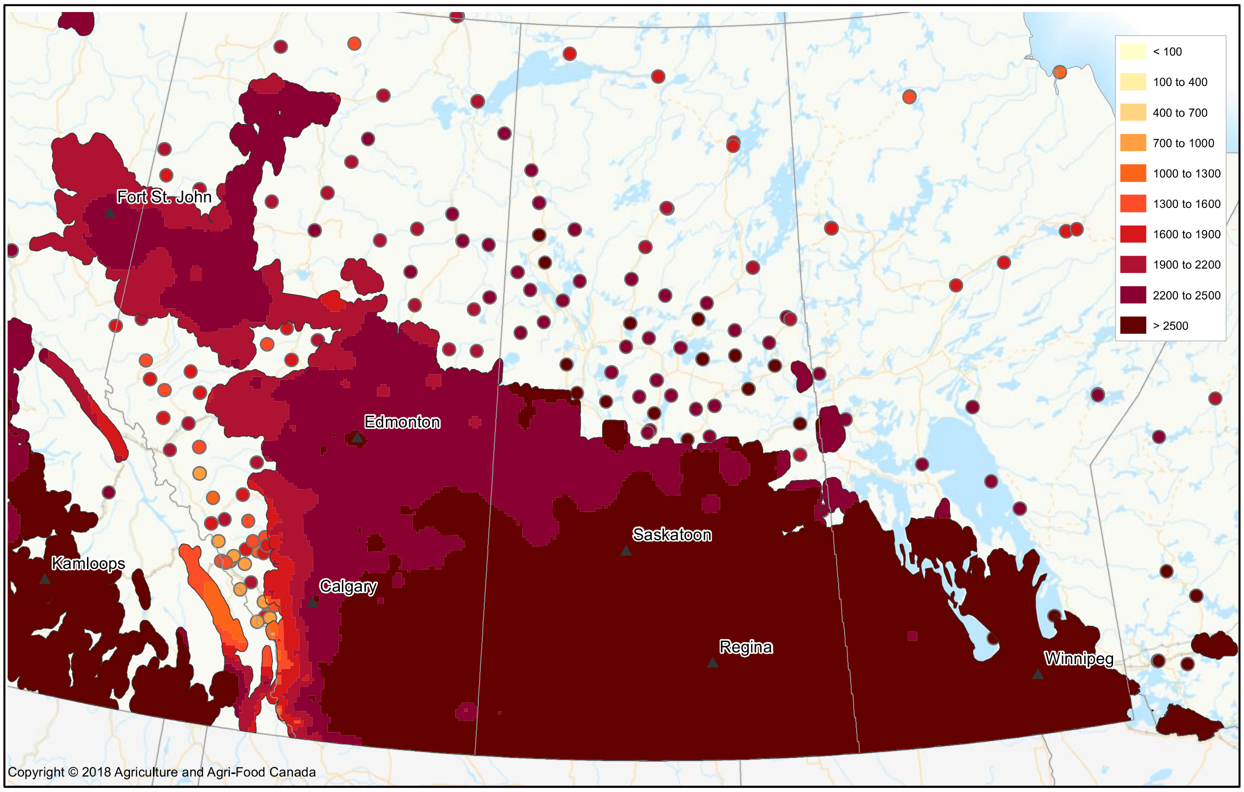

Figure 5.4 Map depicting corn heat units accumulated in western Canada from April 1 to October 31, 2018 (Agriculture and Agri-Food Canada, 2019)

between silage varieties during the backgrounding period, but no differences in animal performance during the finishing period, although at slaughter hot carcass weight was different between varieties. These results suggest that by selecting barley varieties with favourable nutritional characteristics for silage or grain production, producers may be capable of improving the performance of backgrounding and finishing cattle.

Given that regions within western Canada have accumulated CHU exceeding the maturity requirements of several newly developed shorts-season corn varieties in recent years, the likelihood of successful corn grain (**CG**) production in western Canada is increasing. Conventional corn varieties produced for feed in the United States are primarily dent varieties, while short season hybrids grown in western Canada are a combination of flint and dent types. The addition of flint genetics to hybrids produces earlier silking dates, improved drought tolerance, and better adaptability to cooler temperatures. However, flint hybrids also contain an endosperm that is more vitreous than conventional dent varieties produced in the United States, which can result in less degradable starch and protein as they are entwined in a complex matrix that is highly resistant to microbial degradation. As a result, the crude protein (**CP**) content of hybrid flint varieties is generally greater than dent or other conventional corn varieties (Philippeau et al., 1999a; Miorin et al., 2018). Additionally, increased kernel hardness for hybrid varieties necessitates the use of a kernel processor during silage harvest in order to maximize starch digestibility (Miorin et al., 2018). Due to differences between varieties grown, there are also differences in composition of western Canadian short-season corn and conventional corn grown in the United States (Table 2.1; Table 2.2). As previously discussed, Cumberland Valley Analytical Services (CVAS; 2019) reports support that CP content of both corn silage (**CS**) and CG from western Canada is greater than that of corn produced in the Upper Midwest US. Additionally, the ability of short-season hybrids to reach maturity earlier than conventional varieties, often occurs at the expense of a reduction in starch fill, and as a result starch content is generally lower, while NDF and ADF are greater (CVAS, 2019). An alternative explanation for the lower starch and greater NDF and CP could be that the CS produced in western Canada may be more immature at the time of harvest as frost may terminate plant growth and reduce dry matter (**DM**) to concentrations suitable for ensiling. Corn silage used in the present study was greater in starch and CP content, similar in acid detergent fibre (**ADF**) content, and marginally lower in neutral detergent fibre (**NDF**) content than average values reported by CVAS (2019) for western Canadian CS (Table 3.1).

Despite the increasing availability of corn varieties for short-season production, growth of the corn industry in western Canada has occurred primarily in Manitoba, with slower adoption in Saskatchewan and Alberta (Statistics Canada, 2019a). The high cost associated with corn production in combination with lower corn prices may be partially to blame for slower adoption rates. Growth of the corn industry in western Canada poses a challenge to breed varieties of corn that mature rapidly, but also withstand existing pests as well as harsh prairie winds without developing "green snap". This is a condition where strong winds cause breakage of the corn stalks and severely reduce yields. Corn varieties containing the brown midrib (**BMR**) mutant have been found to have reduced lignin content compared to normal corn varieties (Lechtenberg et al., 1972; Cherney et al., 1991). As a silage variety, BMR corn generally exhibits lower DM yields than conventional varieties (Gentinetta et al., 1990; Kohn et al., 2008). Studies evaluating BMR CS have largely focused on dairy cattle. Though results have been variable depending on the stage of lactation or diet formulation, BMR varieties have increased DMI, energy intake, and milk yield as compared to conventional hybrids (Oba and Allen, 2000; Weiss and Wyatt, 2006). Presumably due to lower lignin content, BMR varieties have also been associated with increased in vitro DM an NDF digestibility (Oba and Allen, 2000) as well as increased rumen degradability of DM and organic matter, and increased total-tract NDF digestibility (Greenfield et al., 2001). For steers fed a backgrounding diet, BMR CS resulted in greater ADG, improved G:F, increased total short-chain fatty acid production, increased molar proportion of propionate, and improved economic return relative to conventional hybrids (Saunders et al., 2015). Although desirable, there are currently no short-season BMR varieties available for production in western Canada. Moreover, due to decreased lignin content, stalks of BMR varieties are generally more fragile and lodging remains a concern (Gentinetta et al., 1990). This may be a potential limitation to the successful development of BMR varieties suitable for western Canada, at least in the short-term.

5.2 Impact of Cereal Grain Source and Processing

Expansion of the corn production industry to the prairies has resulted is an increasing availability of CG for cattle feed (Statistics Canada, 2018a). Historically, BS and BG have been the predominant feed sources for feedlot cattle in western Canada due to their regional availability and short growing season. Barley grain contains rapidly degradable starch and protein so simple processing methods such as dry-rolling or temper-rolling are very effective at improving digestibility, as well as reducing costs associated processing infrastructure. As a result, roller mills and tempering systems are commonplace at most feedlots. In recent years, there have been periods where barley prices are high enough that it has been cost-effective to feed CG as an alternative. While simple processing methods are effective at improving digestibility of BG, steam-flaking is the recommended practice to maximize starch digestibility of dry CG. However, for a 20,000 head feedlot, costs of implementation of steam-flaking were estimated at $250,600 compared to just $100,500 for dry-rolling, whereas costs to process 1 tonne of corn were $5.42 greater with steam-flaking as compared to dry-rolling (Macken et al., 2006). Since costs can be prohibitive, corn fed in western Canada is still largely dry- or temper-rolled; practices that may not optimize starch digestibility.

The decision to feed dry-rolled grain in the current study was made such that results would be relevant to current cattle feeding practices in western Canada. Although steam-flaking corn would be ideal, current capacity to steam-flake corn in prairie feedlots is limited. However, in the current studies, low processing severity for CG may have compromised grain utilization as demonstrated by high fecal starch and low starch digestibility in both studies. Though not a new concept, these results support that dry-rolling does not adequately disrupt the complex starch and protein matrix of CG, impairing digestibility (Owens et al., 1997; Zinn et al., 2011).

Though lower than for CG, fecal starch content for BG was still relatively high in Study 1, but despite this fact BG treatments still maintained superior G:F compared to corn. In Study 2, BG contained larger fractions of undegradable DM, CP, and starch when measured *in situ* compared to CG. Although PI was more severe for BG than CG, it is possible that variability in barley kernel size may have resulted in a non-uniform processing with a portion of smaller kernels remaining undamaged and accounting for presence of whole BG in the feces. The importance of uniformity of kernel size in BG processing has been demonstrated to increase DMI as well as CP and ADF digestibility and improve *in situ* starch disappearance (Ahmad et al., 2010; Yang et al., 2013). Though BG maintained greater performance than CG, these results reiterate the potential impacts of kernel variability on nutrient digestibility and the importance of consistency when processing cereal grains.

Though it is difficult to accurately speculate the magnitude, it is likely that steam-flaking CG as opposed to dry-rolling would have improved performance cattle fed CG. Zinn et al. (2011) estimated that steam-flaking improved ADG by 6.3% and decreased DMI by 5.0% compared to dry processed corn. If those values were applied to results from Study 1, DMI (12.2 vs 12.3 kg/d), ADG (2.09 vs 2.21 kg/d), and G:F (0.17 vs 0.18 kg/kg), would be similar between BG and CG fed steer, if not superior for cattle fed CG. Ultimately, these results indicate that at least when dry-rolled, CG is not completely utilized and that until steam-flaking is more readily available in western Canada, dry-rolled barley would be a more desirable grain source in western Canadian feedlot diets.

5.3 Combining Grain Sources for Finishing Diets

In a number of studies, feeding a combination of cereal grains has been demonstrated to have positive associative effects on finishing cattle performance. For instance, Stock et al. (1987b) found that feeding high-moisture corn in combination with diets comprised of whole CG or dry-rolled sorghum improved ruminal and total-tract starch digestion by 14% and 2%, respectively. Kreikemeier et al. (1987) reported improved ADG and G:F when combining dry-rolled wheat, which had 35% greater rate of starch digestion, with dry-rolled corn compared to feeding either grain source independently. When feeding steam-flaked grain sorghum in addition to high-moisture or dry-rolled CG, Huck et al. (1998) observed improvements in ADG and G:F. In contrast, Bock et al. (1991) fed diets composed of high-moisture corn with either dry-rolled or steam-rolled wheat, two rapidly fermentable grain sources, and still observed positive associative effects with regards to feedlot performance. As such, there is a large body of support suggesting that there may be potential additive benefits to combining grain sources that have varying rates and extents of starch degradation.

Several mechanisms have been proposed in an attempt to explain the positive associative effects sometimes observed when feeding a combination of grain sources. Though some authors suggested that improvements were due in part to synchronization of dietary energy and protein sources, there are theories other than nutrient synchrony that have been explored. It is possible that the magnitude of improvement in performance is dependent upon the grain sources being fed, where grain sources that vary greatly in rate and extent of ruminal degradation produce the greatest additive effects. Huck et al. (1998) suggested that performance improvements may have been due to a partial shift in the site of starch digestion from the rumen to the small intestine. Since intestinal digestion of starch has been estimated to provide up to 42% more energy than ruminal starch fermentation (Owens et al., 1986), it is possible that improved energy recovery could account for the benefits observed. Another theory to explain additive effects has been through a reduced risk of ruminal acidosis, by replacing a portion of rapidly fermentable grain with a more slowly fermentable source, thereby reducing the risk of ruminal acidosis and avoiding decreases in DMI due to digestive upsets (Axe et al., 1987; Kreikemeier et al., 1987; Huck et al., 1998). Another possible explanation is that altering ruminal starch digestion may also subsequently influence nitrogen (**N**) use efficiency and microbial protein synthesis (Streeter et al., 1989; Axe et al., 1987; Huck et al., 1998). However, as mentioned previously, benefits to feeding blended grain sources have also been observed when feeding a combination of grain sources with similar fermentability (Bock et al., 1991). This suggests that interactions other than those previously discussed may be partially responsible for associative effects observed.

Despite evidence to support that blending CG and BG, two grain sources with varying rates of starch degradation (2.99 vs 16.23%/hr, respectively), may have resulted in additive effects, no benefit to feeding a blend of carbohydrate sources was observed in either of the current studies. The apparent differences in the rate of starch digestion and effective degradability suggested that fermentability of the two grains should have varied enough to generate additive effects, yet none were observed. In both studies, diets containing a blend of barley and corn grain (**BCG**) largely performed intermediately to either single grain treatment. In Study 1, no parameters measured were improved for BCG diets. In Study 2, a decrease in fecal pH for CG and BCG suggested that starch digestion was partially shifted from the rumen to the small intestine, although there were no other observations suggesting that the energetic efficiency of starch utilization was being improved through intestinal digestion. Though minimum pH was greatest for BS-BG and CS-BCG, maximum pH was greatest for BG and mean pH was numerically greater for BS-BG. The overall trend appeared as though feeding BG resulted a more consistent pH, suggesting that blended grain diets did not aid in preventing ruminal acidosis. Moreover, no differences in bacterial N synthesis were observed, and N retention, in g/d and as a % of intake, was greatest for the CS-BG diet, indicating that blending grain sources was unsuccessful at improving N use efficiency. Despite these few differences measured in Study 2 for the BCG treatments, none were substantial enough to suggest a performance benefit should have been observed for cattle fed BCG diets in Study 1. As such, while there were few differences observed for the BCG treatment, results of the current studies indicate that none of the differences observed are likely to result in additive benefits for finishing cattle performance.

5.4 Silage Effects and the Role of Forage in Finishing Diets

Forage is the predominant feed source on which the cattle industry was created. In many production systems, forage comprises the majority of cattle diets. In finishing diets, sources of forage are included to supply fibre that supports maintenance of normal rumen function, reduces the risk of ruminal acidosis, stimulates rumination, and improves feed intake. A recent survey of 24 feedlot nutritionists consulting throughout the United States indicated that 8 to 10% of DM was the most common forage inclusion level in finishing diets (Samuelson et al., 2016). Relatively recently, studies have been conducted to assess the value of forage in feedlot diets in an attempt to better understand the role that forage plays in high-concentrate diets (Galyean and Hubbert, 2012). The NDF contribution of forages to the diet is a common parameter used to determine if forage content is adequate. For dairy cattle, a more common indicator of forage adequacy is the measurement of physically effective NDF (**peNDF**), which accounts for the ability of forages to contribute to chewing activity, although the importance of peNDF for finishing cattle is not well understood.

Since forages are a cumbersome and costly feed ingredient per unit of energy as compared to grains, a number of studies have evaluated the implications of forage inclusion on finishing cattle performance. Galyean and Abney (2006) evaluated dietary NDF content of 48 studies through multiple regression analysis and noted a strong linear correlation between DMI and net energy of gain (**Neg**) intake with increasing NDF content in finishing diets, suggesting that addition of roughage to high-concentrate diets may increase Neg intake and improve performance. Swanson et al. (2017) compared alfalfa hay, CS, wheat straw, and corn stover included in finishing diets at similar NDF contents, and found that ADG and G:F did not differ. In this same study, authors fed a CS/hay blend at 5%, 10%, 15%, and 20% of DM and found that ADG and G:F linearly decreased with increasing forage , with lowest DMI at 20% inclusion suggesting that while forage source may not alter performance, that inclusion levels > 15% of DM may impair intake and growth performance. In another study, Salinas-Chavira et al. (2013) found that DMI, ADG, and G:F were similar when feeding alfalfa, sudangrass, or rice straw at constant forage NDF levels. They also found that G:F and dietary net energy was improved when fed at 8% as compared to 4% forage NDF, supporting results from Galyean and Abney (2006) that additional forage in finishing diets may be beneficial. Generally, results support that DMI may be increased when feeding forage up to 15% of DM, but higher levels may impair growth performance. Fox and Tedeschi (2002) recommended peNDF levels of 7 to 10% of DM for finishing diets to maintain ruminal pH above 5.7 and avoid drops in DMI. In general, levels used in the industry are often lower than this recommendation.

Perhaps one of the more surprising results of the current studies was the impact that CS inclusion had on carcass quality. At only 8% of DM, CS inclusion increased hot carcass weight and dressing percent compared to BS in Study 1. Given that starch digestibility was greater for BS than CS, and that there was a general lack of other differences between silage sources in Study 1, these results are difficult to explain. Moreover, extremely low *in situ* DM digestibility of both silage sources in Study 2 made it even more perplexing that at such low inclusion (8% of DM) and with such low digestibility, that silage source still had an impact on carcass quality. In Study 1, NIR estimation of total-tract digestibility indicated that starch digestibility was greater for BS than for CS, but these results were not observed in Study 2. Contrarily, *in situ* results in Study 2 supported that DM digestibility was greater for CS after 24 h incubation, and that starch digestibility was also greater for CS at 24-, 48-, and 72-h relative to BS. The near-infrared calibrations developed by Jancewicz et al. (2016b) used for the current study were created based on feedlot diets containing only BS as a forage source. It is possible that due the absence of CS in the calibrations, that DM and starch digestibility may have been underestimated, and could account for the differences in carcass weight and dressing percent observed in Study 1.

The importance of providing a forage source in finishing diets has been well established. Though method of determining adequate forage inclusion levels may vary based on operational preferences, studies indicate that modest increases in forage inclusion level for finishing diets may improve animal performance when included up to 15% of dietary DM. Nevertheless, it is important to recognize that in the current study, even at such low inclusion levels, altering forage source resulted in meaningful changes of carcass quality. Though difficult to interpret, these results may have economic impacts if cattle are sold based on carcass weight or on a grid system rather than live body weight.

5.5 Future Research Considerations

While data from this novel study provides meaningful insight to the influence of common feed sources used in western Canadian finishing diets, results should be carefully interpreted as they represent only one year of silage growing conditions and specific cereal grain processing methods. To the authors knowledge, additional data comparing dry-rolled CG, BG or BCG diets for finishing cattle is currently unavailable. Additionally, there is limited research comparing performance of finishing cattle being fed CS or BS produced in western Canada. As such, current results may be a useful consideration for producers when selecting between corn or barley as grain or silage sources. That being said, there are a still many unknowns regarding forage and silage selection, with specific regard to western Canada. Potential areas for future research considerations may include:

1. The influence of forage source on finishing cattle performance with specific focus on corn and barley silage produced in western Canada.
2. Further research on the impacts of short-season corn silage varieties on finishing cattle performance, with respect to differences between production years and variation in corn silage composition between years.
3. Comparing varying levels of corn or barley silage inclusion on finishing performance.
4. Comparing different ratios of corn and barley grain blends on nutrient utilization and finishing cattle performance.
5. Comparing the effects of altering processing severity or processing method on potential additive effects when feeding blends of corn and barley grain.

6.0 GENERAL CONCLUSION AND IMPLICATIONS

Growth of the short-season corn industry in western Canada has increased the use of corn grain and corn silage for finishing cattle diets. However, there is little research available comparing performance of finishing cattle fed either dry-rolled corn, barley, or a combination of corn and barley grain. Additionally, while previous studies have evaluated the use of either barley- or corn-based diets for finishing cattle, they have not examined the interactions between cereal silage and cereal grain sources. Though it was hypothesized that feeding a combination of corn and barley grains would result in improved total-tract nutrient utilization and improved microbial protein production and ultimately growth performance, there were few positive associate effects observed suggesting that feeding a combination of corn and barley grain may not be beneficial when both grain sources are dry-rolled.

When fed at low levels of inclusion (8% of DM), corn silage resulted in increased hot carcass weight and improved dressing percent. Corn silage is an attractive alternative to barley silage due to increased forage yield often obtained when producing corn silage and the increasing success of corn silage production on the prairies. Results of the current studies suggest that corn silage may be a viable, if not beneficial, alternative to barley silage in western Canadian finishing diets. Feeding barley grain resulted in greater digestibility and G:F, increased rate of digestion, increased total-tract digestibility, and may improve ruminal pH relative to corn grain or diets containing a blend of barley and corn grain. Though, G:F and DMI were similar between cattle fed barley grain and blended grain diets indicating that in circumstances where incorporation of corn grain is cost effective, up to 50% of barley grain may be replaced with corn in finishing diets without dramatically impairing finishing performance. However, cost of additional protein supplementation required when incorporating corn grain into finishing would need to be considered.

The results from this research indicate that there were no observed benefits to feeding a combination of dry-rolled barley and corn grain. With the cereal grain processing practices currently utilized in western Canada, dry-rolled barley grain remains a superior feed grain for finishing cattle relative to corn grain. In addition, there may be potential carcass quality benefits to feeding corn silage compared with barley silage that may be a consideration if marketing cattle based on live weight versus grid or hot carcass weight marketing systems.

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